METHODS FOR IMPROVING SHRIMP FARMING IN CENTRAL AMERICA

USDA UNITED STATES DEPARTMENT OF AGRICULTURE
HURRICANE MITCH RECONSTRUCTION PROJECT

METHODS FOR IMPROVING SHRIMP FARMING IN CENTRAL AMERICA

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1. SHRIMP-CULTURE

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PREFACE

Shrimp farming is an evolving sector of agriculture that creates important economic opportunities in many rural communities plagued by under and unemployment. This water farming practice relies on the wise and responsible use of coastal natural resources and habitats. The long-term, local success of shrimp farming is also influenced by global market forces, consumer preferences and international food safety standards. Advances within the sector depend on accessibility of critical research, educational and laboratory services. Supportive policy, regulation and infrastructure at national and regional levels help creative a conducive business atmosphere. Today's challenges in shrimp farming particularly impact small and medium producers because they are the least likely to benefit from, or have access to, the above mentioned elements that are preconditions for long-term viability of a natural resource based activity.

In October, 1998, Hurricane Mitch caused extensive damage in several countries in Central America, in particular, Honduras and Nicaragua. In response to the widespread losses, the United States Congress appropriated funds to provide assistance in rebuilding damaged infrastructure and services in affected countries, with particular attention to Honduras and Nicaragua, where damages were most severe. Some funds were extended to the U.S. Department of Agriculture's (USDA) Foreign Agricultural Service (FAS) through an interagency agreement with the U.S. Agency for International Development (AID).

Shrimp farming was one of numerous sectors in agriculture identified for Hurricane Mitch reconstruction support based in part on a needs assessment conducted by a USDA-FAS team. USDA responded with development of the Integrated Regional Shrimp Farming Support Program led by the USDA Cooperative State Research, Education and Extension Service and partner U.S. land grant universities with expertise and experience in areas identified as priorities by diverse stakeholders in Mitch Hurricane-affected countries.

This publication is a contribution from the USDA Integrated Regional Shrimp Farming Support Program and was developed by a coordinated effort involving multi-disciplinary expertise from a partnership alliance of seven U.S. universities. Each chapter addresses topics relevant to the long-term development of shrimp farming linked to sound farm-level management decisions that can impact the environment, product quality and safety, profitability, and more. The chapters correspond to training modules presented in a related program component directed at training-the-trainers in Honduras and Nicaragua. The manual and related in-country training programs were designed to strengthen extension outreach capabilities to benefit primarily small and medium shrimp producers. Other program components enhanced disease diagnostic and water quality testing services in Honduras and Nicaragua.

The manual provides technical and science-based information and state-of-art knowledge that can be shared and disseminated broadly to benefit many persons associated with shrimp farming in Central America. The text was reviewed by multi-institutional consultative groups in Honduras and Nicaragua and underwent further peer review by contributing authors and other experts in the field. The manual is a reference for readers from which they can derive new knowledge and gain new skills to improve farming practices and management decisions that promote successful businesses and integration of production systems into sensitive, coastal ecosystems. We are especially pleased that the manual is published in both English and Spanish languages.

Many individuals too numerous to mention by name deserve special thanks and appreciation for their contributions to this unique reference and in-country training activities. In particular, the individuals and teams associated with Auburn University, Texas A&M University, University of Arizona, University of Arkansas-Pine Bluff, University of Florida, University of Hawaii at Hilo, the Coastal Resources Center/University of Rhode Island and Ecocostas (Ecuador) are acknowledged for their contributions to the shrimp sector through this medium.

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SOIL AND WATER QUALITY CONSIDERATIONS IN SHRIMP FARMING

SOIL AND WATER QUALITY CONSIDERATIONS IN SHRIMP FARMING

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INTRODUCTION

Shrimp are delicate creatures that can be stressed by adverse environmental conditions in culture ponds. Shrimp that are stressed do not eat well, they are susceptible to disease, and they grow slowly. By maintaining good environmental conditions in ponds, shrimp farmers can enhance survival, feed utilization efficiency, and production of their crop.

The environment in a shrimp pond consists primarily of the bottom soil and overlaying water, and the main environmental factors affecting shrimp are soil and water quality variables. Effluents from shrimp farms can cause adverse effects on coastal waters by increasing inputs of nutrients, organic matter, and suspended soils. However, negative impacts of effluents are less if ponds are well-managed and good soil and water quality conditions prevail in ponds.

The purpose of this section is to provide information on soil and water quality in shrimp ponds. By reading this section, the shrimp farmer will be better prepared to understand the technical details that follow in other sections. This section also contains the basic principles related to good management practices for use in protecting pond soil and water quality and minimizing adverse impacts in natural ecosystems in the vicinity of shrimp farms.

WATER QUALITY

Warmwater shrimp species grow best at temperatures between 25 °C and 32 °C. Water temperatures are in this range throughout the year in most coastal areas in the tropics. In subtropical areas, water temperatures may fall below 25 °C for periods of several weeks or even several months, and shrimp will not grow well. Thus, two or more shrimp crops are usually produced annually in tropical areas. Only one crop per year can be produced in some subtropical areas, while in others, two crops are produced, but one crop will be li-mited by low water temperature.

Temperature

Temperature has a pronounced effect on chemical and biological processes. In general, biological processes such as growth and respiration double for every 10 °C increase in temperature. This means that shrimp often will grow twice as fast at 30 °C as at 20 °C, and they will use twice as much oxygen at the greater temperature. Therefore, dissolved oxygen requirements of shrimp are more critical in warm water than in cooler water. The growth and respiration of other organisms in shrimp ponds and chemical reactions in pond waters and soils also occur faster as temperature increases. Thus, environmental factors, and particularly water quality variables, become more critical to shrimp production as temperature increases.

In ponds, heat enters at the surface and surface waters heat faster than deeper waters. Because the density of water (weight per unit volume) decreases with increasing temperature above 4 °C, surface waters may become so warm and light that they do not mix with the cooler, heavier waters of deeper layers. The separation of pond waters into distinct warm and cool layers is called thermal stratification. In shrimp ponds, stratification often exhibits a daily pattern. During the day, the surface waters warm and form a distinct layer. At night the surface waters cool to the same temperature as the lower waters and the two layers mix (Figure 1).

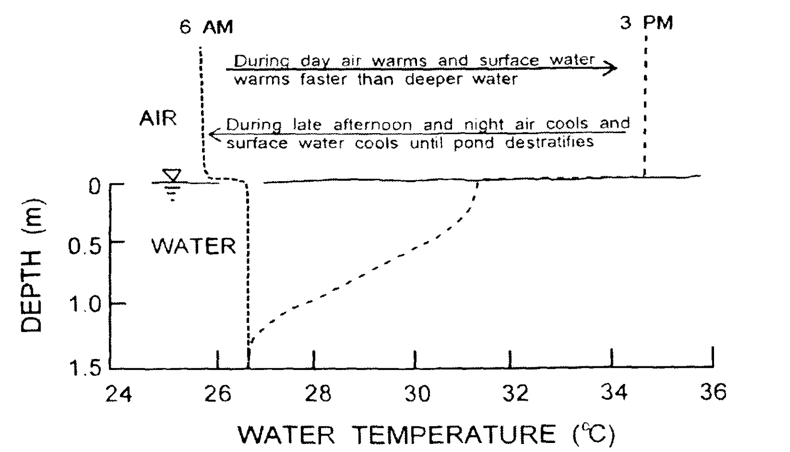

Figure 1. Thermal stratification in a relatively deep pool.

Photosynthesis and Respiration

Plants use carbon dioxide (CO_2), water (H_2O), mineral nutrients, and sunlight to produce organic matter in the form of simple sugars ($C_6H_{12}O_6$) and oxygen (O_2) in photosynthesis. The summary reaction for photosynthesis is:

$$\textbf{Light energy} + 6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2.$$

The simple sugar molecules produced during photosynthesis by green plants represent nearly all of the energy available to living things. Both plants and animals depend upon photosynthetically-produced energy. The simple sugar molecules also are the building blocks for more complex organic compounds. Plants make starch, cellulose, proteins, fats, vitamins, and other compounds from the sugars formed in photosynthesis. Plant tissues are comprised of these compounds, and plants use photosynthetically-derived sugar as an energy source. Animals cannot produce organic matter. They must feed directly on plants or on animals that have fed on plants.

In respiration, organic matter is combined with oxygen (oxidized) with the release of water, carbon dioxide, and energy. Plant and animal cells have the ability to capture some of the energy released through oxidation and to use it to do biological work. The rest of the energy is lost as heat. From an ecological standpoint, respiration is the reverse of photosynthesis:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \textbf{heat energy}$$

When photosynthesis is progressing faster than respiration, oxygen will accumulate and carbon dioxide will decline in pond water. This is the usual situation in a pond during daylight. At night, photosynthesis stops but respiration must continue day and night. Thus, at night oxygen declines and carbon dioxide increases.

The food chain or food web in shrimp ponds (Figure 2) initiates with plants. In ponds the most desirable plants are phytoplankton. These organisms are microscopic algae that are suspended in the water. Algae often are green in color, but some may be blue-green, yellow, red, black, or brown. When pond water contains enough algae to be discolored, it is said to contain a "phytoplankton bloom", or more generally, a "plankton bloom". Algae can grow on the pond bottom where there is sufficient light for photosynthesis. The phytoplankton may be fed upon by microscopic creatures called zooplankton. Collectively phytoplankton and zooplankton are called plankton.

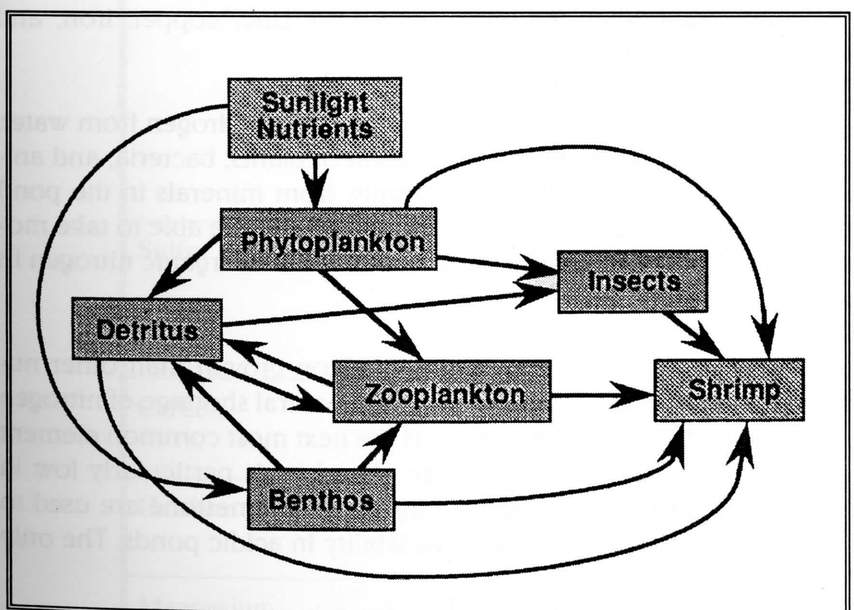

Figure 2. Food chain in a shrimp pond.

The plankton die and fragment to form dead organic matter (detritus) which is food for bacteria, fungi, and other organisms. Detritus settles to the pond bottom; this enriches the soil with organic matter. The pond bottom supports a community of bacteria, fungi, algae, and small creatures called benthos. Aquatic insects are abundant in ponds and feed on plankton, benthos, or detritus. In the shallow areas of ponds with clear water, larger aquatic plants (macrophytes) may grow. However, plankton and benthos are continually dying, and there is usually an accumulation of dead organic matter on the pond bottom called detritus. The natural food of shrimp is mainly detritus, but they also eat plankton, benthos, detritus, aquatic insects, small fish and crustaceans, or some combination of these food organisms.

In order to increase production in ponds, it is necessary to increase the amount of food. This can be done by improving conditions for production of phytoplankton, which, in turn, will increase the production of other natural food organisms. Usually, it is only necessary to add to ponds certain inorganic nutrients in the form of fertilizer to increase phytoplankton growth. However, natural food will not support high levels of shrimp production, and manufactured feed is commonly added to ponds to allow more production than can be achieved in fertilized ponds (Figure 2).

Phytoplankton is extremely important in the dynamics of dissolved oxygen concentrations in ponds. Phytoplankton growth is enhanced by nutrients from fertilizers and feeds. As a result of this, wide variations in dissolved oxygen concentration in water occur between night and day. Excessive phytoplankton blooms may lead to nighttime oxygen depletion and stress or mortality of shrimp. Water quality in ponds is to a large degree dominated by phytoplankton abundance, and the balance between photosynthesis and respiration.

Dissolved and Particulate Substances

A large number of inorganic elements are required for plant growth. Most species require at least the following: carbon, hydrogen, oxygen, nitrogen, sulfur, phosphorus, chloride, boron, molybdenum, calcium, magnesium, sodium, potassium, zinc, copper, iron, and manganese. Diatoms also require silicon.

Aquatic plants make oxygen during photosynthesis, and they obtain hydrogen from water. Carbon dioxide enters water from the air and from respiration of plants, bacteria, and animals. The other elements enter ponds from the water supply, from minerals in the pond bottom, or in additions of fertilizer and feed. Some algae and bacteria are able to take molecular nitrogen (N_2), which enters water from the air, and convert it to organic nitrogen in plant tissue.

Nitrogen and phosphorus are more likely to limit phytoplankton growth than other nutrients. Hence, fertilizers are added to ponds to supplement the natural shortage of nitrogen and phosphorus. After nitrogen and phosphorus, carbon is the next most common element that limits productivity in shrimp ponds. The availability of carbon is particularly low in acidic waters and in waters of high pH. Applications of agricultural limestone are used to neutralize acidity and enhance alkalinity and carbon availability in acidic ponds. The only economical way of improving carbon availability in high pH water is to add organic matter that decomposes to release carbon dioxide. Low concentrations of trace metals, and particularly low concentrations of iron may limit phytoplankton growth in ponds.

Shrimp need adequate concentrations of ions to satisfy their osmotic needs as will be discussed later, but they do not have strict requirements for individual ions. The concentration of dissolved oxygen in the water is a critical factor in the reproduction, growth, survival, and disease tolerance of shrimp. The forms of the various inorganic substances and their desired ranges in shrimp ponds are provided in Table 1.

Table 1. Acceptable concentration ranges for dissolved inorganic substances in aquaculture pond waters.

Element	Form in water	Desired concentration
Oxygen	Molecular oxygen (O_2)	5 - 15 mg/L
Hydrogen	H^+ [$-\log(H^+) = pH$]	pH 7 - 9
Nitrogen	Molecular nitrogen (N_2)	Saturation or less
	Ammonium (NH_4^+)	0.2 – 2 mg/L
	Ammonia (NH_3)	< 0.1 mg/L
	Nitrate (NO_3^-)	0.2 – 10 mg/L
	Nitrite (NO_2^-)	< 0.23mg/L
Sulfur	Sulfate (SO_4^{2-})	500 - 3,000 mg/L
	Hydrogen sulfide (H_2S)	Not detectable
Carbon	Carbon dioxide (CO_2)	1 - 10 mg/L
Calcium	Calcium ion (Ca^{2+})	100 - 500 mg/L
Magnesium	Magnesium ion (Mg^{2+})	100 - 1,500 mg/L

Sodium	Sodium (Na^+)	2,000 - 11,000 mg/L
Potassium	Potassium ion (K^+)	100 - 400 mg/L
Bicarbonate	Bicarbonate ion (HCO_3^-)	75 – 300 mg/L
Carbonate	Carbonate ion (CO_3^{2-})	0 - 20 mg/L
Chloride	Chloride ion (Cl^-)	2,000 - 20,000 mg/L
Phosphorus	Phosphate ion (HPO_4^{2-}), ($H_2PO_4^-$)	0.005 - 0.2 mg/L
Silicon	Silicate (H_2SiO_3, $HSiO_3^-$)	2 - 20 mg/L
Iron[1]	Ferrous iron (Fe^{2+}) Ferric iron (Fe^{3+}) Total iron	0 mg/L Trace 0.05 - 0.5 mg/L
Manganese[1]	Manganese ion (Mn^{2+}) Manganese dioxide (MnO_2) Total manganese	0 mg/L Trace 0.05 - 0.2 mg/L
Zinc[1]	Zinc ion (Zn^{2+}) Total zinc	< 0.01 mg/L 0.01 - 0.05 mg/L
Copper[1]	Copper ion (Cu^{2+}) Total copper	< 0.005 mg/L 0.005 - 0.01 mg/L
Boron[1]	Borate (H_3BO_3, $H_2BO_3^-$)	0.05 - 1 mg/L
Molybdenum[1]	Molybdate (MoO_3)	Trace
Salinity	Sum of all ions	5,000 - 35,000 mg/L

1 The desirable ranges for these substances are poorly understood. The values listed as the desired concentra tions are actually the usual concentrations of these six trace metals in surface waters of ponds.

Pond waters may contain suspended inorganic soil particles. These particles usually enter ponds in the water supply; they are suspended in water by wave action or water currents caused by wind. The larger particles will settle to the pond bottom, but some of the smaller particles may remain suspended for long periods and cause turbidity.

A wide range of organic substances occur in pond water to include sugars, starches, amino acids, polypeptides, proteins, fatty acids, tannins, humic acids, vitamins, etc. Large particles of decaying organic matter called detritus also are plentiful. Of course, the plankton and bacteria also contribute to the organic load in water. Desirable ranges for organic matter concentrations are not known, but pond water usually contains less than 100 mg/L of organic matter.

Organic substances in water, particularly plankton, cause turbidity. Turbidity caused by plankton is desirable as opposed to that produced by suspended clay particles. Ponds are most productive when turbidity by plankton restricts visibility in water to 25 to 40 cm. At this level of plankton abundance, there usually is sufficient natural food, dissolved oxygen is adequate for shrimp, and light does not penetrate to the pond bottom to encourage growth of macrophytes.

Salinity

The total concentration of all dissolved ions is salinity. The salinity results primarily from seven major ions whose average concentrations in seawater follow: sodium, 10,500 mg/L; magnesium, 1,450 mg/L; calcium, 400 mg/L; potassium, 370 mg/L; chloride, 19,000 mg/L; sulfate, 2,700 mg/L; bicarbonate, 142 mg/L. The average salinity of seawater is 34,500 mg/L or 34.5 parts per thousand (ppt). In brackishwater ponds, salinities vary with the salinity of the source water. Estuarine waters may be similar in salinity to freshwater in the rainy season and have higher salinity in the dry season. Some estuaries with restricted connections to the sea have salinities greater than ocean water in the dry season because ions are concentrated through evaporation. Salinity decreases with distance upstream from the mouth of estuaries, and salinity may be stratified with depth in estuaries.

Marine shrimp, such as *Litopenaeus vannamei* and *P. monodon*, can be cultured successfully in coastal ponds over the salinity range of 1 to 40 ppt. However, salinities above 5 ppt are better for shrimp production, and most shrimp farmers prefer a salinity of 20 to 25 ppt in their ponds. Annual variation in salinity of a shrimp pond in Ecuador is provided in Figure 3. Notice that salinity is clearly related to rainfall.

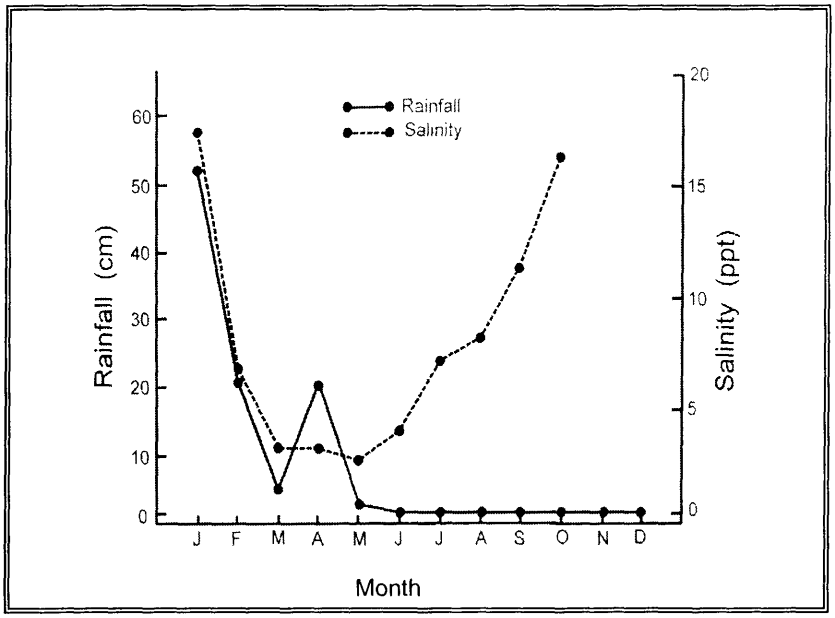

Figure 3. Annual variability in rainfall and salinity in a shrimp pond in Ecuador.

Total Alkalinity

The total concentration of bases in water expressed in milligrams per liter of equivalent calcium carbonate ($CaCO_3$) is the total alkalinity. Bases in water include hydroxide, ammonia, borate, phosphate, silicate, bicarbonate, and carbonate, but in most pond waters, bicarbonate and carbonate greatly exceed other bases in concentration. The alkalinity should be above 75 mg/L in shrimp ponds. Seawater has an average total alkalinity of about 120 mg/L. Alkalinity may decline in waters of low salinity, and alkalinity often declines in ponds with acidic bottom soils.

The total concentration of all divalent cations in water expressed in terms of milligrams per liter of calcium carbonate is the total hardness. The total hardness concentration is about 6,000 mg/L in seawater, and low hardness concentration is not considered an important factor in most shrimp ponds.

Biochemical Oxygen Demand

Biochemical oxygen demand (BOD) is a measure of the rate of oxygen consumption by the plankton and bacteria in a sample of pond water. A sample of raw water or diluted water is incubated in the dark for 5 days at 20 °C. The loss of dissolved oxygen from the water during the incubation period is the biochemical oxygen demand.

Shrimp ponds typically have BOD values of 5 to 10 mg/L. The higher the BOD, the greater the degree of enrichment of pond water with organic matter. Oxygen depletion is a danger in ponds without mechanical aeration when BOD exceeds 20 mg/L. The BOD is not used much in aquaculture pond management, but it is commonly used in estimating the pollutional strength of effluents. Because of the recent concern over the influence of pond effluents on water bodies into which they are released, environmental management is expected to become a major issue in aquaculture. Thus, the aquaculturist should be famiexpected to become a major issue in aquaculture. Thus, the aquaculturist should be familiar with BOD.

Secchi Disk Visibility

The Secchi disk is a 20-centimeter diameter disk painted with alternate black and white quadrants (Figure 4). It is weighted on the bottom of the disk and attached at the center of its upper surface with a calibrated line. The depth at which the disk just disappears from view is the Secchi disk visibility. Obviously, care must be taken to standardize the procedure for reading the Secchi disk. In many waters, there is a close correlation between Secchi disk visibility and plankton abundance. As plankton density increases, visibility decreases. However, if waters contain much turbidity from suspended clay particles or detritus, the Secchi disk visibility will not be suggestive of phytoplankton abundance. The general relationship between Secchi disk visibility and the condition of the plankton is provided in Table 2.

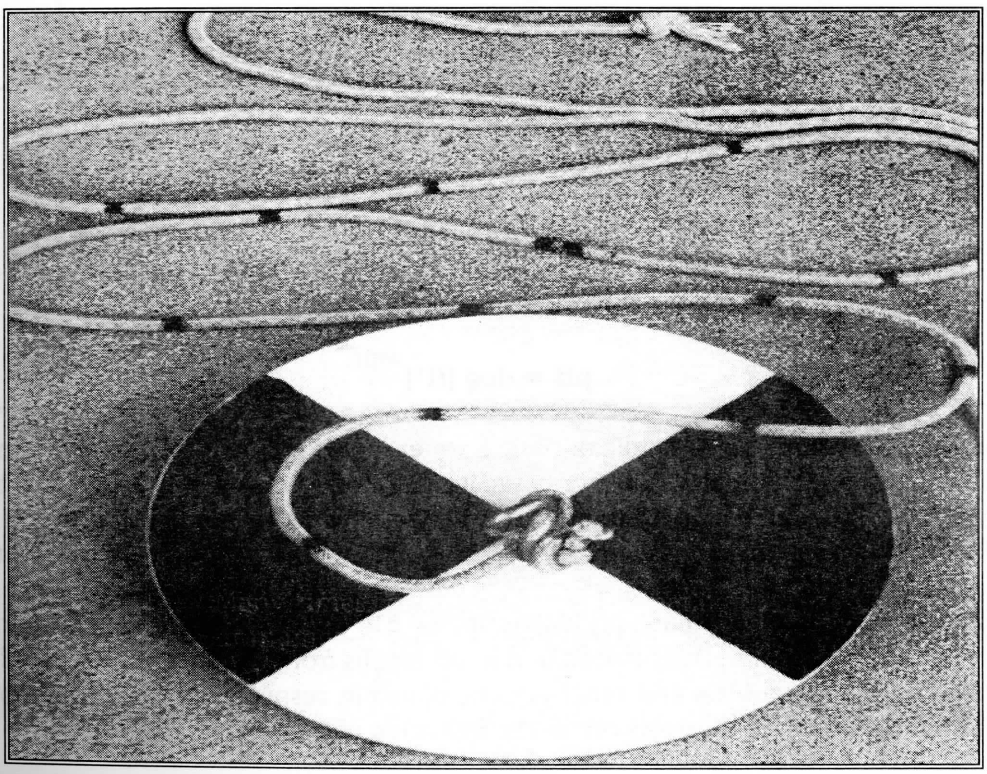

Figure 4. Secchi disc.

Table 2. Relationship between Secchi disk visibilities and conditions of phytoplankton blooms.

Secchi disk reading (cm)	Comments
Less than 25 cm	Pond too turbid. If pond is turbid with phytoplankton, there will be problems with low dissolved oxygen concentrations. When turbidity is from suspended soil particles, productivity will be low.
25-30 cm	Turbidity becoming excessive.
30-45 cm	If turbidity is from phytoplankton, pond is in good condition.
45-60 cm	Phytoplankton becoming scarce.
More than 60 cm	Water is too clear. Inadequate productivity and danger of aquatic weed problems.

pH

The pH is defined as the negative logarithm of the hydrogen ion (H+) concentration:

$$pH = -\log [H^+]$$

More simply, pH indicates how acidic or basic a water is. For practical purposes, water with a pH of 7 is considered neither acidic nor basic; it is said to be neutral. When the pH is below 7, the water is said to be acidic. Water with a pH above 7 is considered basic. The pH scale extends from 0 to 14; the more the pH differs from 7, the more acidic or basic the water.

Brackish water ponds usually have pH values of 7 or 8 in the early morning, but afternoon pH often increases to 8 or 9. Daily fluctuation in pH results from changes in the rate of photosynthesis by phytoplankton and other aquatic plants in response to the daily photoperiod. Carbon dioxide is acidic as shown in the following equation:

$$CO_2 + H_2O = HCO_3^- + H^+$$

If carbon dioxide concentration increases, hydrogen ion concentration increases and pH decreases. Conversely, if carbon dioxide concentration decreases, hydrogen ion concentration falls and pH rises. Thus, when phytoplankton removes carbon dioxide from the water during daylight, the pH of water increases. At night, no carbon dioxide is removed from the water by phytoplankton, but all pond organisms release carbon dioxide in respiration. As carbon dioxide accumulates in the water at night, the pH falls.

The daily cycle in pH is illustrated in Figure 5. The daily fluctuation in pH is not always as great as shown in this figure, but wide pH fluctuation can result when phytoplankton is abundant. Ponds with moderate or high total alkalinity usually have higher pH values in the early morning than ponds with low total alkalinity. However, when phytoplankton is abundant, much higher afternoon pH values occur in ponds with low alkalinity than in ponds with greater alkalinity. This results because of the buffering capacity afforded by the higher alkalinity.

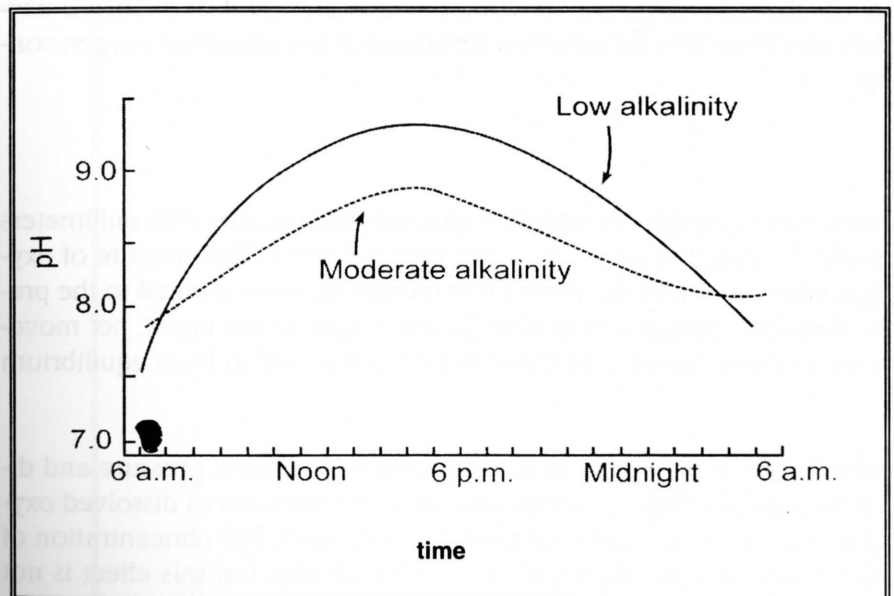

Figure 5. Effects of alkalinity on diurnal pH variation.

The direct influence of pH on shrimp is generalized below:

Effect	pH
Acid death point	4
No reproduction	4-5
Slow growth	4-6
Best growth	6-9
Slow growth	9-11
Alkaline death point	11

Where the pH of pond water is too low, lime may be applied to improve pH. Low pH is more common than high pH. This is fortunate, for there is no reliable procedure for reducing high pH. Usually, acidity problems in ponds do not result from direct effects of low pH on growth, reproduction, or survival, but from the effects of low alkalinity and acidic muds on plankton and benthic production. The effects, of course, are reflected in low shrimp production. In some coastal areas, soils contain from 1 to 5% sulfur in the form of iron pyrite. Such soils are called potential acid sulfate soils. If ponds are built in such material and pyri-tic soil is exposed to the air in levees or watershed, oxidation of pyrite can result in formation of sulfuric acid. This acid can leach into ponds and cause an extremely low pH.

Dissolved Oxygen

Dissolved oxygen is the most critical water quality variable in shrimp culture. Shrimp farmers need to thoroughly understand factors affecting the concentration of dissolved oxygen in pond water. They also should be aware of the influence of low dissolved oxygen concentrations on shrimp.

Solubility

The atmosphere contains 20.95% oxygen. At standard atmospheric pressure (760 millimeters of mercury), the pressure of oxygen in air is 159.2 mm (760 X 0.2095). The pressure of oxygen in air drives oxygen into water until the pressure of oxygen in water is equal to the pressure of oxygen in air. When the pressure of oxygen in water and air are equal, net movement of oxygen from air to water ceases, and dissolved oxygen is said to be at equilibrium or saturation.

The solubility of dissolved oxygen at saturation for standard atmospheric pressure and different temperatures is provided in Table 3. Notice that the concentration of dissolved oxygen at saturation declines markedly as water temperature increases. The concentration of dissolved oxygen at saturation also declines with increasing salinity, but this effect is not great over the salinity range for freshwater aquaculture. At high salinity, water holds considerably less dissolved oxygen than at low salinity. The concentration of dissolved oxygen at saturation decreases with decreasing barometric (atmospheric) pressure. Shrimp farms are located at sea level, and changes in barometric pressure in response to weather conditions are small. This change in dissolved oxygen solubility resulting from pressure changes may be ignored in shrimp farming.

Table 3. The solubility of oxygen (mg/L) in water at different temperatures and salinities from moist air with pressure of 760 mm Hg.

Temperature (°C)	Salinity (ppt)								
	0	5	10	15	20	25	30	35	40
0	14.60	14.11	13.64	13.18	12.74	12.31	11.90	11.50	11.11
1	14.20	13.72	13.27	12.82	12.40	11.98	11.58	11.20	10.82
2	13.81	13.36	12.91	12.49	12.07	11.67	11.29	10.91	10.55
3	13.44	13.00	12.58	12.16	11.76	11.38	11.00	10.64	10.29
4	13.09	12.67	12.25	11.85	11.47	11.09	10.73	10.38	10.04
5	12.76	12.34	11.94	11.56	11.18	10.82	10.47	10.13	9.80
6	12.44	12.04	11.65	11.27	10.91	10.56	10.22	9.89	9.57
7	12.13	11.74	11.36	11.00	10.65	10.31	9.98	9.66	9.35
8	11.83	11.46	11.09	10.74	10.40	10.07	9.75	9.44	9.14
9	11.55	11.18	10.83	10.49	10.16	9.84	9.53	9.23	8.94
10	11.28	10.92	10.58	10.25	9.93	9.62	9.32	9.03	8.75
11	11.02	10.67	10.34	10.02	9.71	9.41	9.12	8.83	8.56
12	10.77	10.43	10.11	9.80	9.50	9.21	8.92	8.65	8.38
13	10.52	10.20	9.89	9.59	9.29	9.01	8.73	8.47	8.21
14	10.29	9.98	9.68	9.38	9.10	8.82	8.55	8.29	8.04
15	10.07	9.77	9.47	9.19	8.91	8.64	8.38	8.13	7.88
16	9.86	9.56	9.28	9.00	8.73	8.47	8.21	7.97	7.73
17	9.65	9.36	9.09	8.82	8.55	8.30	8.05	7.81	7.58
18	9.45	9.17	8.90	8.64	8.38	8.14	7.90	7.66	7.44
19	9.26	8.99	8.73	8.47	8.22	7.98	7.75	7.52	7.30
20	9.08	8.81	8.56	8.31	8.06	7.83	7.60	7.38	7.17
21	8.90	8.64	8.39	8.15	7.91	7.68	7.46	7.25	7.04
22	8.73	8.48	8.23	8.00	7.77	7.54	7.33	7.12	6.91
23	8.56	8.32	8.08	7.85	7.63	7.41	7.20	6.99	6.79
24	8.40	8.16	7.93	7.71	7.49	7.28	7.07	6.87	6.68
25	8.24	8.01	7.79	7.57	7.36	7.15	6.95	6.75	6.56

26	8.09	7.87	7.65	7.44	7.23	7.03	6.83	6.64	6.46
27	7.95	7.73	7.51	7.31	7.10	6.91	6.72	6.53	6.35
28	7.81	7.59	7.38	7.18	6.98	6.79	6.61	6.42	6.25
29	7.67	7.46	7.26	7.06	6.87	6.68	6.50	6.32	6.15
30	7.54	7.33	7.14	6.94	6.75	6.57	6.39	6.22	6.05
31	7.41	7.21	7.02	6.83	6.64	6.47	6.29	6.12	5.96
32	7.29	7.09	6.90	6.72	6.54	6.36	6.19	6.03	5.87
33	7.17	6.98	6.79	6.61	6.43	6.26	6.10	5.94	5.78
34	7.05	6.86	6.68	6.51	6.33	6.17	6.01	5.85	5.69
35	6.93	6.75	6.58	6.40	6.24	6.07	5.91	5.76	5.61
36	6.82	6.65	6.47	6.31	6.14	5.98	5.83	5.68	5.53
37	6.72	6.54	6.37	6.21	6.05	5.89	5.74	5.59	5.45
38	6.61	6.44	6.28	6.12	5.96	5.81	5.66	5.51	5.37
39	6.51	6.34	6.18	6.02	5.87	5.72	5.58	5.44	5.30
40	6.41	6.25	6.09	5.94	5.79	5.64	5.50	5.36	5.22

Plants growing in pond water produce oxygen in photosynthesis, and during daylight, plants may produce oxygen so fast that dissolved oxygen concentrations in water rise above saturation. Water containing more dissolved oxygen than expected for the existing barometric pressure and water temperature is said to be supersaturated with dissolved oxygen. Water also may contain less dissolved oxygen than expected at saturation for prevailing conditions. Respiration by organisms in ponds may cause dissolved oxygen levels to decline; dissolved oxygen typically declines below saturation at night.

When water is below saturation with dissolved oxygen, there is a net movement of oxygen molecules from air to water. At saturation with dissolved oxygen, the number of oxygen molecules leaving the water equals the number entering; there is no net movement of oxygen molecules. Net movement of oxygen molecules from water to air occurs when water is supersaturated with dissolved oxygen. The larger the difference between the pressure of oxygen in water and air, the greater is the net exchange of oxygen molecules.

The degree of saturation of water with dissolved oxygen (DO) frequently is expressed as percentage saturation. The equation for estimating percentage saturation is:

$$\% \text{ Saturation} = \frac{\text{DO concentration in water}}{\text{DO concentration at saturation}} \times 100$$

For example, if the barometric pressure is 760 mm, the water temperature is 25 °C, the salinity is 20 ppt, and the dissolved oxygen concentration is 9.0 mg/L, the percentage saturation is (9.0 / 7.36*) x 100 = 122.3%.

Effects on shrimp

The influence of dissolved oxygen concentrations on shrimp is summarized below:

Concentrations of dissolved oxygen can fall so low that shrimp die. However, adverse effects of low dissolved oxygen more often are expressed as reduced growth and greater susceptibility to disease. In ponds with chronically low dissolved oxygen concentrations, shrimp will eat less and they will not convert food to flesh as efficiently as in ponds with normal dissolved oxygen concentrations.

Dissolved oxygen concentration	Effect
Less than 1 or 2 mg/L	Lethal if exposure last more than a few hours.
2-5 mg/L	Growth will be slow if exposure to low dissolved oxygen is continuous.
5 mg/L-saturation	Best condition for good growth.
Above saturation	Can be harmful if supersaturated conditions exist throughout pond volume. Normally, there is no problem.

Plankton and dissolved oxygen

Light passing through pond water is rapidly reduced, and the rate of quenching increases as the amount of particulate matter (turbidity) in the water increases. As a result, photosynthesis occurs most rapidly in the surface layer of water, and dissolved oxygen concentrations decline with depth. Plankton blooms reduce light penetration, and the amount of light available for photosynthesis at a given depth is proportional to the amount of plankton. In ponds with a lot of plankton, dissolved oxygen concentrations may fall to 0 mg/L at depths of 1.5 or 2 m (Figure 6). Because of this, it is best to use relatively shallow ponds (1.0 to 1.5 m) for shrimp culture.

*See Table 3. At 25 °C and a salinity of 20 ppt, the solubility of oxygen is 7.36 mg/L.

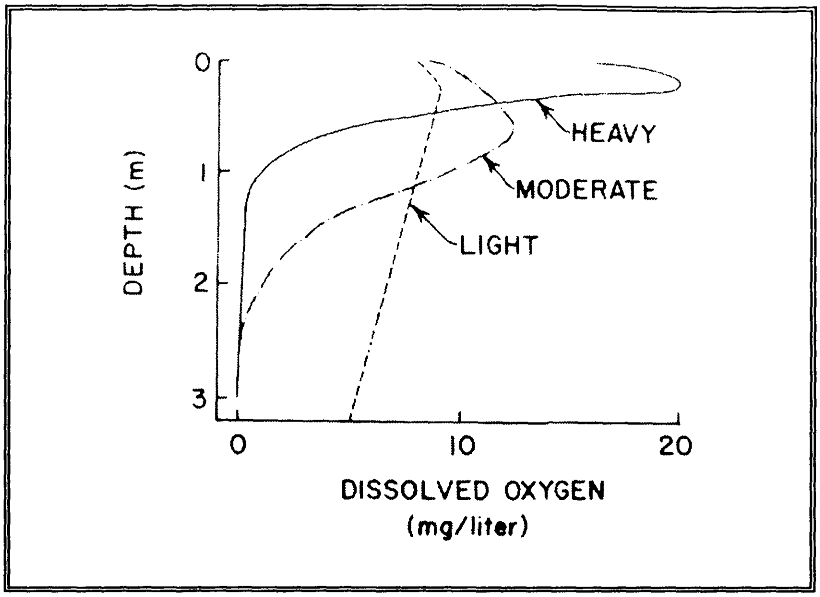

Figure 6. Dissolved oxygen levels according to pond depth.

Concentrations of dissolved oxygen exhibit a daily cycle. The lowest concentrations of dissolved oxygen occur about dawn. During daylight, photosynthesis causes dissolved oxygen concentrations to increase, and maximum dissolved oxygen concentrations are reached in the afternoon. During the night, photosynthesis ceases, but continuing use of oxygen by pond organisms causes dissolved oxygen concentrations to decline. The daily cycle in dissolved oxygen is most pronounced in ponds with heavy phytoplankton blooms (Figure 7). Although the influence of the daily cycle of dissolved oxygen on growth of shrimp is poorly understood, good growth usually can be achieved as long as the dissolved oxygen concentration does not fall below 30 or 40% of saturation during the night and does not remain at this low level for more than 1 or 2 hours.

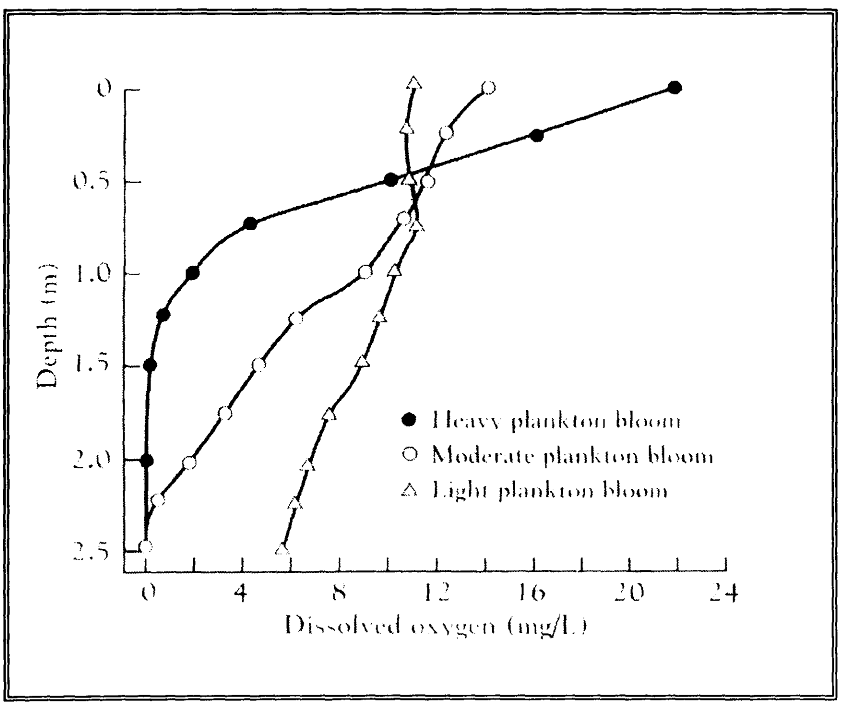

Figure 7. Variation in dissolved oxygen levels with depth and degree of phytoplankton bloom.

Cloudy weather can influence dissolved oxygen concentrations as illustrated in Figure 8. This results because cloudy weather reduces the rate of photosynthesis through light limitation, but it has little or no effect on respiration. The influence of cloudy weather is more pronounced in a pond with a heavy phytoplankton bloom than in a pond with less phytoplankton.

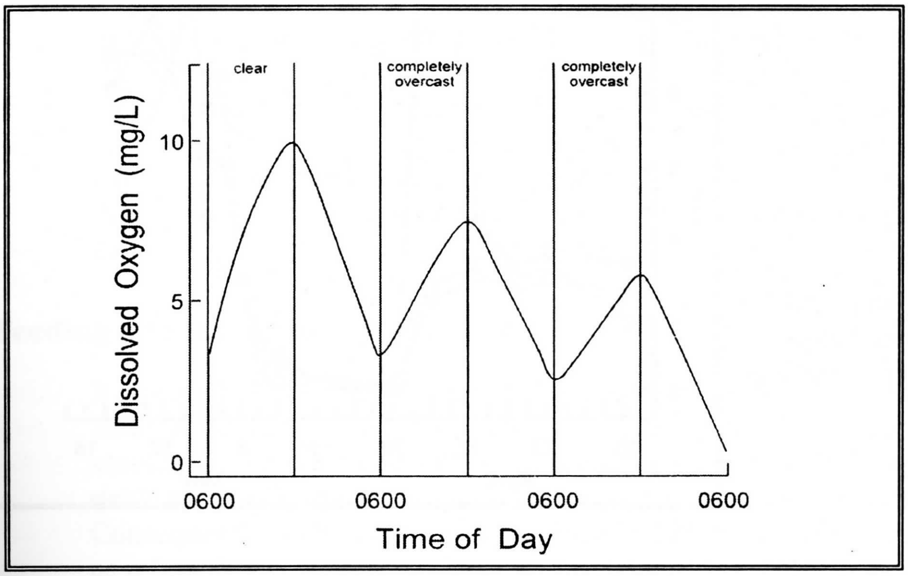

Figure 8. Effect of cloudy weather on dissolved oxygen concen trations.

In summary, as fertilization or feeding rates are increased in shrimp ponds, phytoplankton abundance increases. This permits greater aquacultural production, but it also causes dissolved oxygen concentrations to fluctuate widely between day and night and to decrease with depth. If fertilization or feeding rates are too high, phytoplankton blooms will become so dense that growth of shrimp will decline or they will die because of low dissolved oxygen concentrations.

The shrimp farmer must adjust the fertilization or feeding rates so that there is both adequate plankton and dissolved oxygen for shrimp. Because of differences in responses of individual ponds to fertilization and feeding, it is not possible to recommend a single, maximum safe fertilizer or feed application rate and schedule suitable for all ponds. It is essential that the pond manager observe each pond carefully and adjust fertilizer and feed applications to fit pond conditions.

Phytoplankton in ponds may suddenly die and decompose causing depletion in dissolved oxygen. An example of a phytoplankton die-off is shown in Figure 9, and the influence of the die-off on dissolved oxygen concentrations is illustrated in Figure 10. The dissolved oxygen concentrations did not return to normal until a new phytoplankton bloom was established. Most phytoplankton die-offs involve species of blue-green algae. During calm weather, blue-green algae often form scum at pond surfaces. Intense sunlight may result in sudden death of algae in this scum. Blue-green algae have high concentrations of nitrogen in their tissue, so they decompose rapidly.

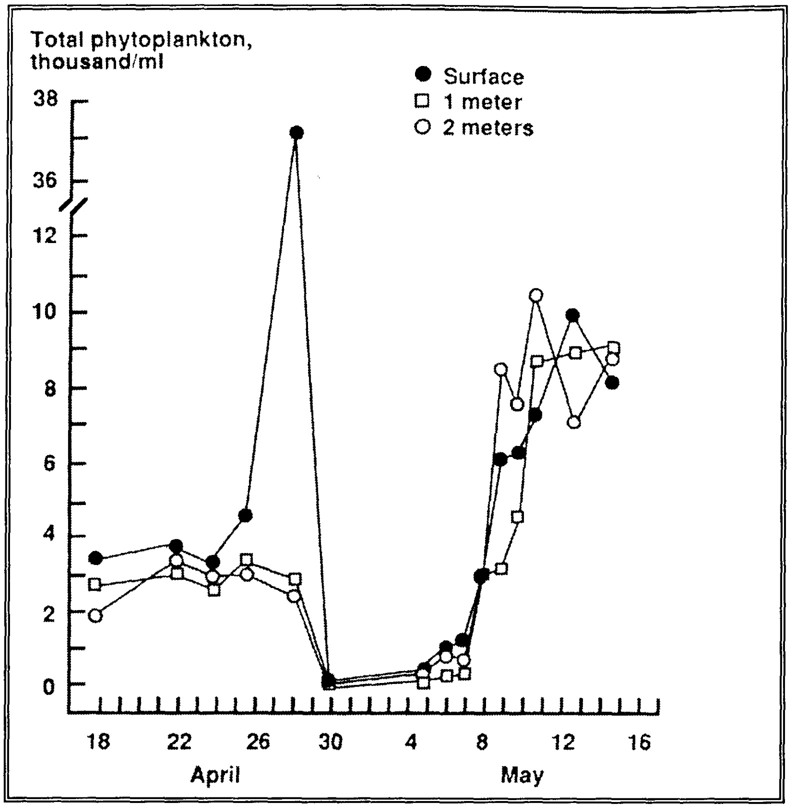

Figure 9. Changes in phyto plankton abundance before, during and after a phytoplankton die-off.

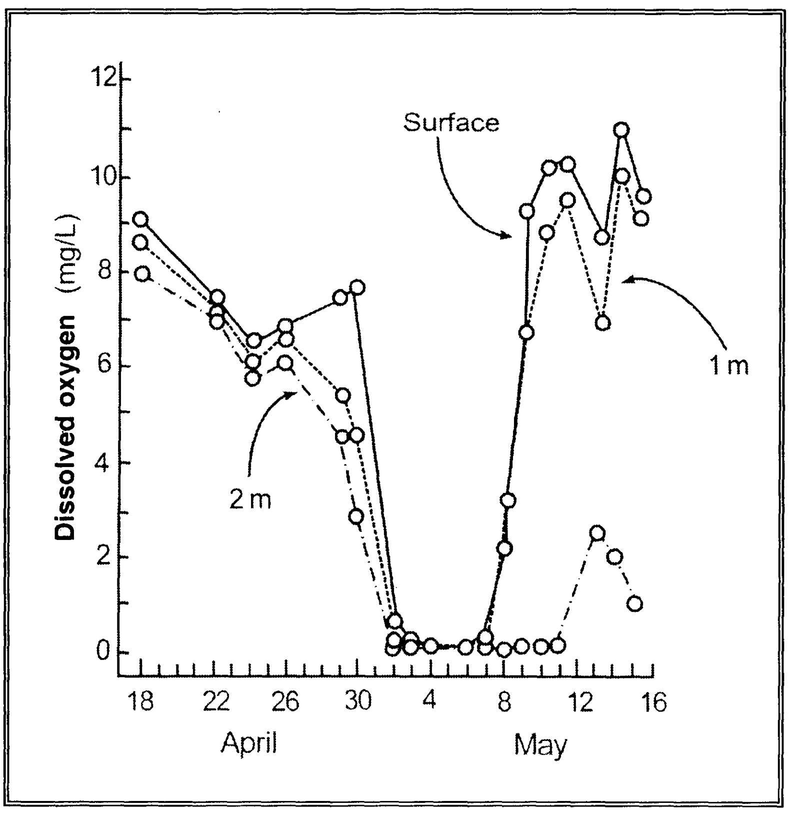

Figure 10. Influence of phytoplankton die-off on dissolved oxygen levels.

Mats of filamentous algae that develop on pond bottoms may, under certain conditions, float to the surface of a pond and die. This phenomenon also can cause depletion of dissolved oxygen.

Sediment oxygen

Although plankton abundance usually is the dominant factor in dissolved oxygen dynamics in shrimp ponds, the bottom sediments also consume dissolved oxygen. Bottom sediments, especially in old ponds where large amounts of organically-enriched sediment have accumulated, may exert large oxygen demands. There has been little research on dissolved oxygen consumption rates by pond soils, but there is evidence that respiration by the benthic community can easily remove 2 to 3 mg/L of dissolved oxygen from the pond water in 24 hours.

Feeding and dissolved oxygen

It already has been shown that phytoplankton abundance is controlled by nutrient supply, and that dissolved oxygen concentrations are regulated to a large extent by phytoplankton abundance. Feed applied for shrimp results in pollution of pond waters by organic and inorganic metabolic wastes. Uneaten feed also decomposes, releasing nutrients into the water. Consequently, phytoplankton abundance and problems with low dissolved oxygen increase as a function of increasing feeding rate (Figure 11). These data suggest that feeding rates above 30 or 40 kg/ha per day will result in unacceptably low dissolved oxygen. Higher feeding rates may be used in ponds if water exchange rates are high or if mechanical aeration is applied.

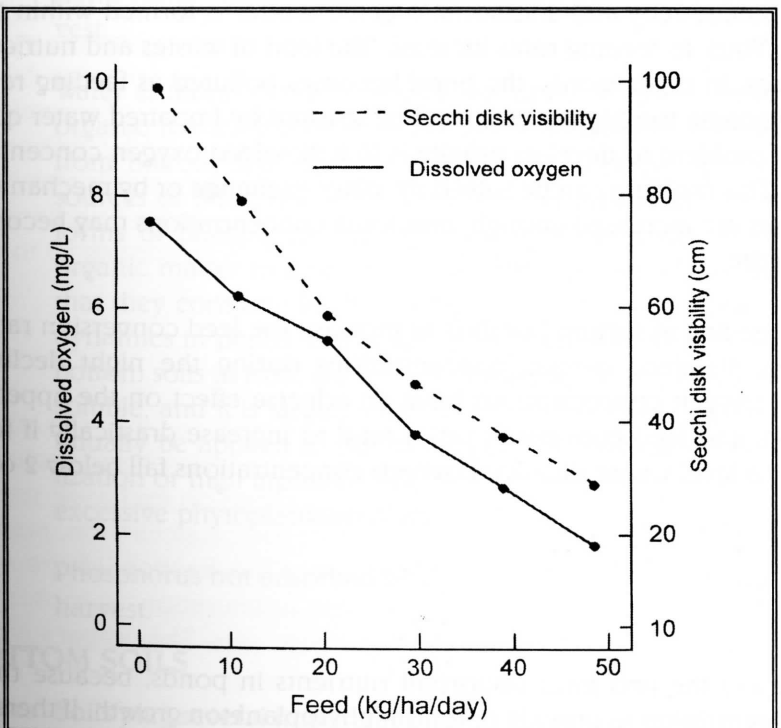

Figure 11. Effect of feeding rate on dissolved oxygen concentrations at dawn and on Secchi disk visibilities.

The feed conversion ratio is determined as the quantity of feed applied divided by the net production (shrimp harvested minus initial stocking weight). For example, suppose that a 1-ha pond had a net production of 1,500 kg of shrimp and 2,700 kg of feed had been applied. The feed conversion ratio is:

$$\frac{2{,}700 \text{ kg feed}}{1{,}500 \text{ kg shrimp}} = 1.80.$$

A low feed conversion ratio indicates greater efficiency than a high value. With good management practices, feed conversion ratios of 1.5 to 2.0 may be achieved with shrimp.

Commercial shrimp feeds do not usually contain more than 5 or 10% moisture, but shrimp are about 75% water. Dry matter feed conversion ratios are much larger than the feed conversion ratios computed by dividing live net production weight into amount of feed. In shrimp culture, 1,800 kg of feed might produce a net of 1,000 kg of live shrimp. The feed is about 92% dry matter, so the input of dry matter is 1,656 kg. The shrimp are about 25% dry matter, so they contain about 250 kg of dry matter. The dry matter feed conversion ratio is 6.62. Thus, 5.62 kg of dry weight equivalent of metabolic wastes and uneaten feed reach the pond during the production of 1,000 kg of live shrimp.

This dry matter contains nutrients that are released to the pond water by shrimp respiration and excretion and by microbial decomposition of uneaten feed and feces. These nutrients stimulate phytoplankton productivity and additional organic matter is formed within the pond ecosystem by algae. Thus, as feeding rates increase, the load of wastes and nutrients to the pond water increases. In other words, the pond becomes polluted as feeding rates increase. If feeding rates become too high, shrimp will be stressed by impaired water quality. The first water quality problem to develop usually is low dissolved oxygen concentration in the early morning. This problem can be solved by water exchange or by mechanical aeration, but if feeding rates are increased enough, ammonia concentrations may become high enough to cause toxicity.

One of the effects of overfeeding in shrimp ponds is to increase the feed conversion ratio. As feeding rate increases, dissolved oxygen concentrations during the night decline. Chronically low dissolved oxygen concentrations have an adverse effect on the appetite and metabolism of shrimp, and feed conversion ratios tend to increase drastically if feeding rates are increased to a level where dissolved oxygen concentrations fall below 2 or 3 mg/L each night.

Nitrogen and Phosphorus

Nitrogen and phosphorus are the two most important nutrients in ponds, because they should be in adequate concentration to provide optimum phytoplankton growth. If there is too little nitrogen and phosphorus, there will be too little phytoplankton, clear water, and a shortage of natural shrimp food. If there is too much nitrogen and phosphorus, phytoplankton will be excessive and dissolved oxygen depletion will be problematic during the night.

The main sources of nitrogen for plants are ammonia nitrogen and nitrate nitrogen. Nitrogen contained in organic matter (organic nitrogen) is converted to ammonia nitrogen as bacteria decomposed organic matter. Ammonia nitrogen can be converted to nitrate nitrogen by nitrifying bacteria. Water entering ponds contains ammonia nitrogen, nitrate nitrogen, and organic nitrogen, and organic nitrogen occurs in pond sediment. Some bacteria and blue-green algae can convert nitrogen gas, which dissolves in water from the atmosphere, to organic nitrogen by a biological process known as nitrogen fixation. However, this process usually is not important in shrimp ponds. In shrimp ponds, the major sources of nitrogen are feed and fertilizers. Usually, 20 to 40% of nitrogen in feed or natural food eaten by shrimp is converted to nitrogen in shrimp tissue. The rest is excreted into the water as ammonia nitrogen. Uneaten feed is decomposed by bacteria and ammonia nitrogen is released into the water. Thus, as feeding rates increase, ammonia nitrogen concentrations increase in the water, and they can reach potentially toxic levels.

Nitrogen removed from water by plants tends to be recycled when the plants die. Nitrogen is lost from ponds through denitrification in which certain bacteria convert nitrate to nitrogen gas. This process usually occurs in anaerobic sediment. Ammonia nitrogen can diffuse from pond water into the air, and this process is favored by high pH and wind blowing over pond surfaces. Nitrogen also is lost from ponds in outflowing water and in shrimp at harvest.

Water entering ponds also contains phosphorus in dissolved inorganic phosphate and in organic matter. Small amounts of phosphorus also may be released into the pond water from bottom soil. Natural concentrations of phosphorus usually are low, so the major sources of phosphorus are feeds and fertilizers. As with nitrogen, plants absorb inorganic forms of phosphorus (phosphate) from the water and bacteria convert phosphorus in organic matter to inorganic form. Shrimp also release about 60 to 80% of the phosphorus that they consume back into the water. The major difference in nitrogen and phosphorus dynamics in ponds, is that 60% or more of the phosphorus entering ponds accumulates in bottom soils as iron, aluminum, or calcium phosphates. Soil-bound phosphorus is not very soluble, and it is largely unavailable to the organisms in the pond. Phosphorus must continually be applied to ponds to maintain phytoplankton blooms. Nevertheless, over-fertilization or high inputs of feed can increase phosphorus concentrations in water and cause excessive phytoplankton abundance.

Phosphorus not adsorbed by pond soil is lost in outflowing water or removed in shrimp at harvest.

BOTTOM SOILS

Soils play several important roles in shrimp ponds. The bottom soils and earth-fill embankments of ponds serve as the basin in which pond water stands. Bottom soils store and release both nutrients and organic matter, and they provide a medium for growth of benthic organisms and associated bacteria. These organisms may serve as shrimp food, and they also recycle nutrients and degrade organic matter.

Pond soils are derived from terrestrial soils. However, conditions in pond bottoms are different from conditions in surface, terrestrial soils. Organic matter added to or produced in ponds, suspended solids entering ponds in runoff, and particles re-suspended from the pond bottom by water currents are continually deposited on the pond bottom to form a layer of sediment. Dissolved oxygen concentrations are usually low in pond water of bottom sediment and organic matter decomposition progresses at a slower rate than in terrestrial soil. Also, carbonates, ferric hydroxide, and phosphate commonly precipitate from pond water into sediment. Pond bottoms tend to be the final recipient of residues of substances that are added to or produced in the pond.

Texture

The texture of a soil refers to the proportion of gravel, sand, silt, and clay particles in the soil. Particle size analysis of an agricultural soil provides the percentages of sand, silt, and clay from which a soil texture name, e.g. sandy, clayey loam, etc., may be assigned with the aid of a soil triangle (see any general soil text). There is little value in the agricultural soil classification scheme in studies of pond soils. However, it is good to know how much clay is in a pond soil, for the clay is the reactive fraction. Soil also contains organic matter, and organic matter, like clay, is highly reactive.

There is a common misconception that pond soils should have a high clay content to prevent seepage. Soils for making pond bottoms and levees should contain some clay, but 10 to 20% clay content usually is enough provided the soil contains particles of several size fractions. Soils containing 25% or more of clay particles often are very sticky, difficult to spread and compact during construction, and levees made from such materials may have a tendency to slip. Also, drying and other treatments of heavy clay bottom soils between crops often are difficult. Nevertheless, many sites for shrimp farms often contain 25 to 50% clay.

Acidity and pH

Clay and finely-divided organic particles in soil are negatively charged, and they can adsorb and exchange positively charged ions (cations). The ability of soils to adsorb and exchange cations is called the cation exchange capacity. The cations adsorbed on exchange sites in soils are acidic (aluminum ion, ferric ion, and hydrogen ion) or basic (calcium ion, magnesium ion, potassium ion, sodium ion, and ammonium ion). The fraction of the total exchange capacity occupied by acidic ions is called the base unsaturation. In most soils, there will be very little hydrogen ions or ferric ions on exchange sites. The primary acidic ion is aluminum ion.

The acidic reaction of aluminum may be visualized as follows:

$$\text{Al-Soil} = Al^{3+} + 3H_2O = Al(OH)_3 + 3H^+$$

As the base unsaturation of a soil increases, the amount of aluminum ion available to react with water and form hydrogen ion increases. Therefore, soil pH decreases with increasing base unsaturation.

The way in which liming neutralizes acidity in mud is illustrated in Figure 12 using calcium carbonate as the liming agent. Calcium carbonate reacts with hydrogen ions and neutralizes them. This lowers the concentration of hydrogen ions in solution and more aluminum ions are released from the soil. Aluminum ions released from the soil are replaced by calcium ions resulting from the neutralization of hydrogen ions by calcium carbonate. The end results are: aluminum is removed from the soil and precipitated as aluminum hydroxide; calcium replaces the aluminum on the soil; the base unsaturation of the soil decreases; the pH of the soil increases.

The best pH range for shrimp pond soil is considered to be 7 to 8. Seawater and estuarine water have high concentrations of sodium and other basic ions. Thus, bottom soils in shrimp ponds often have base saturated soils and soil pH above 7.

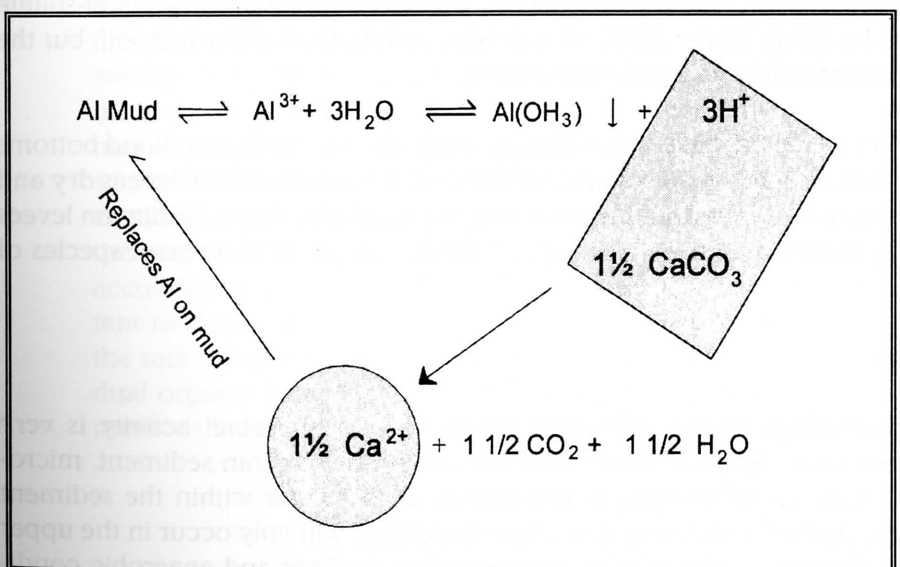

Figure 12. Neutralization of soil acidity by use of lime (calcium carbonate).

Ponds sometimes are constructed in areas once covered by brackish water tidal swamps and marshes. When rivers with a heavy sediment load emptied into the sea, sediment was deposited near the shore. After the deposits rose above mean low water level, vegetation became established. As deposition continued, the coast slowly accreted, and a swamp forest developed. In the swamp forest, tree roots trapped organic and inorganic debris, and decomposition of dense masses of organic debris resulted in anaerobic conditions. As a result, sulfur reducing bacteria became abundant and sulfide produced by the bacteria accumulated in pore spaces in sediment as hydrogen sulfide or combined with iron to form precipitates of iron sulfides. Iron sulfides underwent further chemical reaction to form iron disulfides that crystallized to form iron pyrite.

As long as sediments containing pyrites are submerged and anaerobic, they remain reduced and change little. However, if they are drained and exposed to the air, oxidation results, and sulfuric acid is formed. The summary reaction for sulfuric acid formation from iron pyrite is:

$$FeS_2 + 3.75\ O_2 + 3.5\ H_2O \longrightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

The ferric hydroxide crystallizes as a reddish brown material in the sediment. After draining, a sediment containing pyrite is called a potential acid-sulfate soil or a "cat's clay". Potential acid-sulfate soils are found most commonly in existing or former mangrove areas. Thus, if such areas are not included in shrimp farms, problems with acid-sulfate soils usually can be avoided.

Under aerobic conditions, acid-sulfate soil will have a pH below 4.0. The pH of acid-sulfate soils often will decrease as much as 3 units upon drying. Field identification of acid-sulfate soils can sometimes be made by the smell of hydrogen sulfide from disturbed soil, but the positive test is to measure pH before and after drying.

In ponds, the problem with acid-sulfate soils usually originates on the levees. Pond bottoms are usually flooded and anaerobic, so sulfuric acid does not form. However, levees dry and sulfuric acid formed during dry periods enters ponds in runoff after rains. Acidity on levees can be controlled by liming and establishing good cover with an acid-resistant species of grass.

Organic Matter

Organic matter accumulates at the soil water interface, and microbial activity is very intense in this surface layer. Because water does not move freely within sediment, microbial activity quickly reduces the oxygen concentration in the water within the sediment (pore waters). Usually, aerobic conditions (presence of oxygen) will only occur in the upper few millimeters of sediment. As the oxygen concentration declines and anaerobic conditions develop in soils, reduced substances such as nitrite, ferrous iron, manganous manganese, hydrogen sulfide, methane, and many organic compounds appear in the soil as the result of chemical reactions and the respiration of anaerobic bacteria.

The degradation of organic matter in the mud causes the low dissolved oxygen condition, and the continued degradation of the organic matter results in the reduction of the inorganic substances. Thus, organic matter is the source of the reducing power that often leads to high concentrations of nitrite, ammonia, ferrous iron (Fe^{2+}), divalent manganese ion, hydrogen sulfide, and methane in pond mud. The absence of oxygen in sediment may slow down the rate of organic matter decomposition, but it does not halt decomposition. In fact, anaerobic conditions are normal in pond sediment, and aquaculture pond soils do not normally accumulate large amounts of organic matter unless inputs of organic matter are excessive. For example, in ponds with large inputs of manures, bottom soils may accumulate large amounts of organic matter. Nevertheless, if organic matter inputs to pond bottoms are so great that aerobic conditions cannot be maintained at the soil-water interface, shrimp may be exposed to reduced and potentially toxic substances.

The iron reaction in water provides a means of determining if the surface layer of a mud is anaerobic. In the absence of oxygen, ferric iron (Fe^{3+}) is converted to ferrous iron (Fe^{2+}). Ferrous iron is black in color. Therefore, when the surface of the mud is black, anaerobic conditions exist. When the surface is brown or the natural soil color, it suggests that oxygen is present. Of course, if you break through the aerobic surface layer of a mud, deeper layers will be anaerobic and black. It is highly desirable to maintain dissolved oxygen in the upper layer of sediment. Shrimp food organisms that live in mud require oxygen, and the presence of oxygen in the mud prevents formation of noxious reduced substances.

There is considerable interest in the amount of organic matter in pond sediment. However, evaluation of data on organic matter concentrations in pond soil is difficult. Because organic matter settles onto the bottom and is then decomposed and gradually mixed with deeper layers by physical and biological processes, the organic matter concentrations quickly decrease with sediment depth. The upper, flocculent layer of recently-deposited sediment may have an organic content of 50% or greater, but the organic content of the entire upper 1 to 2 cm layer seldom will exceed 10% except where ponds are built on soils with high concentrations of native organic matter (organic soils). When the organic matter decomposes, the most readily decomposable material is degraded first and the more resistant material accumulates. Therefore, much of the organic residue in pond soils consists of material resistant to decay. The problem of excessive oxygen demand in bottom sediment is related to the rate of input of fresh, labile organic matter rather than to the amount of resistant, residual organic matter that has accumulated over time. At present, we do not have reliable methods for readily distinguishing between these two types of organic matter.

TOXIC METABOLITES

As a result of metabolic activity by organisms in ponds, carbon dioxide, ammonia, and hydrogen sulfide sometimes may reach harmful concentrations.

Carbon Dioxide

Shrimp can survive in waters containing up to 60 mg/L of carbon dioxide, provided dissolved oxygen concentrations are high. When dissolved oxygen concentrations are low, the presence of appreciable carbon dioxide hinders uptake of oxygen. Unfortunately, carbon dioxide concentrations normally are high when dissolved oxygen concentrations are low. This results because carbon dioxide is released in respiration and utilized in photosynthesis. Dissolved oxygen concentration declines when photosynthesis is not proceeding as rapidly as respiration; thus, carbon dioxide accumulates, because it is not removed for use in photosynthesis.

Because of the necessity of light for photosynthesis, carbon dioxide concentrations increase at night and decrease during the day. High concentrations of carbon dioxide also occur in ponds during cloudy weather and following die-offs of phytoplankton or filamentous algae.

Removing carbon dioxide from pond waters is seldom practical.

Ammonia

Ammonia nitrogen occurs in water in two forms, un-ionized ammonia (NH_3) and ammonium ion (NH_4^+), in a pH and temperature dependent equilibrium:

$$NH_3 + H_2O = NH_4^+ + OH^-$$

As pH rises, un-ionized ammonia increases relative to the ammonium ion. Water temperature also causes an increase in the proportion of un-ionized ammonia, but the effect of temperature is less than that of pH. The toxicity of ammonia to aquatic organisms is attributed primarily to the un-ionized form. Ammonia concentrations in shrimp ponds seldom reach lethal concentrations, but concentrations high enough to stress shrimp are not uncommon. Shrimp pond waters usually have pH values around 8, and at this pH, total ammonia nitrogen concentrations as high as 10 mg/L probably would not kill shrimp. However, to avoid stress, concentrations above 2 mg/L should be avoided.

High ammonia concentrations are most common in ponds with high feeding rates. Excessive use of urea or ammonium-based fertilizers such as ammonium sulfate also can lead to toxic concentrations of ammonia. The only feasible means of reducing ammonia concentration is water exchange. Claims about the effectiveness of zeolite and bacterial amendments for removing ammonia appear false in pond environments.

Nitrite

Nitrite may accumulate to concentrations of 10 to 20 mg/L in water of aquaculture ponds under certain conditions. At high concentrations, nitrite combines with hemocyanin in shrimp blood and greatly reduces the ability of the blood to transport oxygen. In semi-intensive shrimp culture, nitrite seldom exceeds 1 or 2 mg/L, and toxicity is not a problem. There have been occasional reports of nitrite toxicity in intensive shrimp culture.

Hydrogen sulfide

Under anaerobic conditions, certain heterotrophic bacteria can use sulfate and other oxidized sulfur compounds as terminal electron acceptors in metabolism and excrete sulfide as illustrated below:

$$SO_4^{2-} + 8H^+ = S^{2-} + 4H_2O$$

Hydrogen sulfide normally is produced by bacteria in anaerobic pond soil and diffuses into the pond water where it is oxidized to sulfate. Nevertheless, residual concentrations may occur in pond water when the release of sulfide from bottom soil is high. Sulfide is an ionization product of hydrogen sulfide and participates in the following equilibrium:

$$HS^- = S^{2-} + H^+$$

The pH regulates the distribution of total sulfide among its forms (H_2S, HS^-, and S^{2-}). Un-ionized hydrogen sulfide (H_2S) is toxic to aquatic organisms; the ionic forms have no appreciable toxicity. The proportion of un-ionized hydrogen sulfide decreases rapidly with increasing pH. Nevertheless, hydrogen sulfide is extremely toxic to shrimp, and any detectable concentration should be considered undesirable.

If water contains hydrogen sulfide, water exchange will reduce its concentration. Application of lime to raise the pH of the water will reduce the proportion of the total sulfide that is comprised of hydrogen sulfide.

POLLUTION OF SOURCE WATER

Water pollution in source water can have serious consequences on shrimp hatcheries and shrimp farms, so the prevent of contaminants in source water is an important consideration in site selection and in shrimp hatchery, shrimp farm, and shrimp processing plant operations. The most common pollutants are heavy metals, pesticides and other agrochemicals, industrial chemicals, and coliforms organisms. The analyses of most pollutants are difficult and expensive to make, and the interpretation of data from such analyses also may be problematic. Moreover, there are many ions and compounds that are considered pollutants, and it is not feasible to analyze water for all possible pollutants. The first approach should be to consider the types to contaminants that have the opportunity to contaminate the water source. Heavy metals occur naturally, but unless soils in the area are highly acidic (pH below 5), natural concentrations of metals such as iron, manganese, zinc, copper, chromium, lead, mercury, cobalt, molybdenum, aluminum, cadmium, etc., would rarely be harmful to shrimp. The other main source of heavy metals would be industry, but some heavy metals are used in agriculture. Thus, a survey of the area could reveal if there are sources of heavy metal which might contaminate the water source and harm shrimp. Pesticides are used in agriculture, in mosquito and other human pest control, and by home owners to protect gardens from insects and other pests. A survey also could reveal the extent of pesticide use in the area and the types of pesticides used. Only those pesticides used in the area could occur in the water. A similar survey should be made for industrial chemicals. Coliform organisms could be a problem by contaminating shrimp at harvest by contaminating the product during processing. Coliforms in source water originate from fecal material of warm-blooded animals. Fecal coliforms indicate contamination with human feces.

If a survey suggests that specific metals, pesticides or organic chemicals are a possible problem, analyses for the specific compounds can be made. These analyses must be made on carefully collected and preserved samples by a qualified laboratory. The laboratory should be consulted on how to collect, store, and transport samples. The laboratory should be able to provide some recommendation of the possibility of toxicity to shrimp by specific compounds or ions based on concentrations. However, a specialist from a university, governmental agency, or private consulting firm usually should be consulted regarding the possibilities for toxicity and means for dealing with the contamination. This topic is too complex to cover in greater detail in this manual.

Abundance of coliform bacteria is an important variable in the water source, because contamination of the product can occur during harvest if pond waters are contaminated, or after harvest, if freshwater supplies used in processing and handling are contaminated. The total coliform bacteria level in water is normally around 1,000 to 2,000 MPN (most probable number) /100ml (average is 10 to 20/ml) and the normal fecal coliform bacteria count usually is less. Total coliforms can originate from many sources, but fecal coliforms indicate contamination by feces from warm blooded animals. The median fecal coliform bacterial concentration in swimming water should not exceed 200/ml and for shellfish harvesting should not exceed 14 MPN/100 ml. Waters used in processing (washing, freezing) should meet drinking water standards which is 10 MPN/100 ml for total coliforms and 0 MPN/100ml for fecal coliforms.

POND EFFLUENTS

Water discharged from shrimp ponds during routine water exchange and for harvest contains nutrients, organic matter, and suspended solids. These substances represent potential pollutants because they can cause water quality deterioration in receiving waters. Thus, effluents are considered to be a major environmental problem in shrimp farming.

A literature review (Boyd and Gautier 2000) provided the following average concentrations of water quality variables in effluents from semi-intensive shrimp ponds.

Variable	Average	Range
pH	7.9	7.5-8.5
Dissolved oxygen (mg/L)	5.5	2-8
Total suspended solids (mg/L)	79	25-200
Total ammonia nitrogen (mg/L)	0.2	0.01-0.5
Total nitrogen (mg/L)	0.95	0.2-2.7
Soluble reactive phosphorus (mg/L)	0.05	0.01-0.15
Total phosphorus (mg/L)	0.28	0.1-0.4
5-day biochemical demand (mg/L)	5.5	2-14

Thus, water from shrimp ponds is not highly concentrated in potential pollutants, and it usually has pH and dissolved oxygen concentrations within acceptable limits. The variable that appears most problematic, with respect to concentration limits often placed on water quality variables in effluents, is the suspended solids. The total suspended solids concentration in shrimp pond effluents tend to be rather high, and especially in the final 20 to 25% of water discharged when ponds are emptied for shrimp harvest.

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2

SITE SELECTION

Site selection

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Introduction

The selection of a suitable site is an important step toward making an aquaculture project a success. The site selected depends upon a number of important criteria that will be discussed in this chapter. Site selection is crucial because it can determine the pond design, farm layout, supportive infrastructure, production methodology, management strategy, and hatchery location.

Initial Considerations Prior to Site Visit

Before the potential aquaculture site is selected and visited, the objectives and constraints of the organization proposing to establish the operation should be determined. A market survey and analysis is recommended. Marketing tests should also be conducted. Unless the project is completely integrated and the farm will have its own processing capacity, the processing plant in the area is usually the market outlet for producers. Most large farms are integrated and sell to a world market where competition is fierce. Know your market channels and understand what it takes to produce a high quality and wholesome product that meets international food safety standards (see Chapter 8).

Once the market is researched and tested, the goal for production volume can be set. The type of production technology (extensive, semi-intensive, intensive) best suited for your company and the site must also be decided. Determine how many crops per year are desired and possible at the site. Lastly, assess how much land is required, which is a function of the targeted production level, crops per year and production technology. The species to be cultured should be chosen and overall productivity from the farm should be predicted as accurately as possible. The site can be selected to suit the desired species, or a species can be selected that will be best suited for a particular site.

The projected financial returns of the project should be assessed, and the probability of meeting preset economic return thresholds should be evaluated in light of the specific circumstances in a proposed site. Because of the many failures in the industry, most investors and lending institutions consider aquaculture a high risk. Most lenders are more likely to consider funding a project if it has been tested on a demonstration scale at the chosen site. A management team with proven experience and plans to work full time at the site also increases credibility.

Lending institutions will not be interested in the project unless it meets a given internal rate of return threshold (see Chapter 9). Generally the projected financial returns are much higher than the actual returns because there are many unexpected costs; therefore, the financial assessment should be done very conservatively. In the author's opinion, if the internal rate of return is projected to be above 20% and preferably in the 30-50% range over a 12 year horizon, then the site selection process should be continued. Depending upon the company's goals, if the projected returns fall below 20% per annum then the project should be curtailed before any further funds are expended. In most cases, obtaining credit or financing for shrimp operations is difficult. Generally, entrepreneurs entering the business for the first time must have added assets (such as already owning the land) or previous experience to that makes meeting the projected financial return probable in order to secure financing.

Other Important Aspects To Consider In The Site Selection Process

The political stability in the area should be assessed and unstable areas avoided. It is important that aquaculture sites be located away from any significant sources of pollutants. These include agricultural runoff (from crop spraying for example), sewage out-falls (municipal and industrial), storm runoff canals, harbors, and refineries. Water samples should be collected and tested on a routine basis. This will create a data base to monitor possible contamination, help in enforcing existing regulations, assist in designing clean-up operations in severely impacted areas, if they are needed, and assist in identifying suitable sites for aquaculture development in the future. It is also important that the site not be located in wetlands, mangrove areas, or any other environmentally sensitive location. Most locations now have laws governing commercial development in these areas. An environmental assessment is strongly recommended whether required by law or not as shrimp farmers are ultimately responsible for preventing environmental impacts. An environmental assessment is also a useful tool to accompany the site selection process since it yields useful information for the planning process. In some cases, it may be possible to utilize certain areas through mitigation although caution should be taken since many environmentally sensitive areas possess characteristics that are not conducive to good production (i.e. mangroves).

Sources of Site Information

If the financial analysis is favorable, then all possible sources of information concerning the prospective site should be evaluated before the site is visited and more detailed information collected. These sources might include, but are not limited to: the internet; fisheries reports; regional development plans; zoning regulations; local, state, and national government aquaculture regulations; economic development plans; remote satellite sensing; aerial photographic surveys; oceanographic surveys; hydrological surveys; land use surveys; soil type surveys; and engineering and topographical surveys in the area.

Site Assessment Involves Gathering the Following Information

The next step would be to visit the site and gather as much information as possible through personal reconnaissance and by reviewing topographical, hydrological, meteorological and biological data. A site and zone description or general description of the entire area should be obtained. More specific information about the site such as specific location (map or coordinates), types of vegetation, water, roads, and drainage potential should be obtained. Obtain the following information while on the site assessment trip:

1. **General Information on Site:** Information should be collected on the location, map, access, wave action, water salinity at high and low tide, water pH, elevation above seawater source, land topography, benthic composition, distance of seawater and freshwater sources, type of inlet prescribed, water depth at inlet site, pollution potential, organics in water, turbidity, potential for flooding, source of broodstock/price/conditions, electrical power, freshwater source, aquaculture distributors in area, source of trained workers, and potential for well.

2. **Detailed Information on Site and Land Details:** Determine the total amount of land available, expansion potential, current or previous use, owner, land prices, lease terms available if any, and topography. Details of land ownership and conditions of use must be investigated.

3. **Soil details for construction purposes:** Sampling should occur throughout the site. Note location of soil samples, depth taken, soil type and stability according to soil type. A map of the sampled area is helpful.

4. **Seawater Quality Details at Site:** Identify potential sources, distance from site, color of water, storm potential, beach appearance, erosion, accretion, freshwater plume, proximity of river, tidal flux, type of tide - either diurnal or semi-diurnal, navigation traffic, industrial activity on or near source, and description of nearest port.

5. **Freshwater Details at Site:** Collect information on the nearest river, size of river, other sources of freshwater, rainy and dry season river depth and width, estimated hydraulic flow during seasons, potential for flooding, last major flood damage, distance of freshwater source from site, potential for well, pipeline or canal, potential sources of effluent, and agricultural pollution.

6. **Meteorological Data at Site:** Determine the duration of dry and rainy seasons, evaporation rates and temperature variance in seasons.

7. **Flora and Fauna at Site:** Describe the marine and freshwater fisheries and obtain any relevant data, distance to broodstock and fishing grounds, typical fishing vessels, and nearest fishing port.

8. **Infrastructure/Utilities/Resources at Site:** Evaluate the electrical supply, nearest transformer, type of current, capacity, cost of electricity, potential for power shortages, petroleum and other lubricant availability, building materials, laboratory equipment, heavy construction equipment, and computers. Transportation routes and accessibility to the site should be identified and evaluated.

9. **Socio/Economic Data at Site:** Gather information on the nearest city, industries, labor force, construction contractors, engineers, aquaculturists, university and research backup, business schools in area, nearest village or town, local industries, local government, political peace and tranquility or unrest, other aquaculture projects such as hatcheries or farms in the area, and extent of government assistance. Potential impacts (negative and positive) should be broadly identified at this stage and further investigated during the site visit (see below).

Additional information and Rationale

A description of the climate in the region should be obtained, including air and water temperature, wind, rainfall, solar radiation and evaporation. Air temperature is pertinent because it can change the temperature of the water. Wind and solar radiation also influence water temperature. Air temperature data (°C or °F) should be recorded if local data are unavailable.

Water temperature is important because it determines which species will grow best at the site or which species should be grown during a particular season. The following serves as an example of pre-existing water temperature data found during a site assessment for a tropical shrimp farm:

Month	A.M. temp. (°C)	(° F)	P.M. temp. (°C)	(° F)
Dec.	22-23	(71.6-73.4)	26-28	(78.8-82.4)
Jan.	22	(71.6)	24	(75.2)
Feb.	19-20	(66.2-68)	21-23	(69.8-73.4)
Mar.	25	(77)	28	(82.4)
Apr.	21-25	(69.8-77)	29-32	(84.2-89.6)
May	26-27	(78.8-80.6)	31	(87.8)
June	27-30	(80.6-86)	31-33	(87.8-91.4)
July	No data	No data	No data	No data
Aug.	29	(84.2)	33-35	(91.4-95)
Sept.	No data	No data	No data	No data
Oct.	22-24	(71.5-75.2)	25-32	(77-89.6)
Nov.	19-27	(66.2-80.6)	28-30	(82.4-86)

From these pre-existing records it appears that the cool months will be November through February (or four months out of the year) and the warmer afternoon temperatures of concern fall in the month of August. These data can be useful in assisting management decisions on species to culture during the different seasons.

The prevailing or dominant wind direction should be obtained. This information can assist in pond design and layout. Wind has three major effects on water in culture ponds: (i) it circulates the water, thus mixing the layers of differing density that tend to form in ponds (stratification). This helps oxygen and phytoplankton-rich surface waters to reach the organism being grown. It also moves low oxygen water, with higher concentrations of waste (metabolites), to the surface, thus encourages re-oxygenation and stimulates the biodegradation of metabolites; (ii) it tends to lower the water temperature by increasing evaporative cooling; and (iii) it generates waves in a pond that erode pond banks.

Hurricanes, typhoons and large storms do occur in some locations and may be a definite threat to a site. Storm winds can rip out pond liners if water is not in the pond, or destroy tanks and raceways if they are not weighted with water. A storm surge can cause flooding and loss of a crop in tanks, raceways and ponds or cause erosion and dike collapse in ponds. For example, Hurricane Mitch caused much damage to the aquaculture industry in Central America in 1998. The availability of insurance should be investigated.

Average yearly precipitation for the site should be obtained. Rainfall influences aquaculture in several ways: (i) it dilutes saltwater, thus lowering salinity; (ii) it can erode pond banks, roads, etc.; (iii) it promotes the growth of erosion preventative grasses on the pond dikes; and (iv) it lowers water temperatures.

In the tropics, rains are intense and seasonal. Heavy rains may cause damage to the dikes and roads, while the long period of dry weather discourages the growth of protective vegetation. On the other hand, monsoon rains usually tend to lower pond water temperatures during the hottest time of the year when they need to be somewhat lower. Rainfall data are generally available from government sources such as a national weather service.

The main concern of rainfall is flood potential. One should try and obtain the 20, 100 or even 200 hundred-year flood plain data for the area, if available. Try to obtain the maximum intensity of rainfall recorded, the duration, frequency, yearly precipitation data, and watershed characteristics. Rainfall, soil properties, types of vegetative cover, topography, and the extent of the watershed draining the area determine the flooding potential. The outer dike or perimeter dike elevation is generally based on the highest known flood and its height.

There is usually a definite season of low water temperatures at any given site, even in the tropics. Solar radiation influences water temperature and growth of phytoplankton in ponds. Phytoplankton relies on sunlight to convert carbon dioxide into carbon and oxygen. Carbon is essential for growth, and oxygen is released into the environment. Phytoplankton is fundamental to pond grow-out technology. Not only does it provide the primary production in the natural food chain, but it is also the major source of dissolved oxygen (DO) in ponds. In addition, phytoplankton binds or converts certain toxins (like metabolites), thus purifying the water. However, in the absence of sunlight, phytoplankton becomes a net consumer of oxygen. Thus, during prolonged periods of overcast weather, DO may be depleted. This may stress aquatic animals, inhibiting their growth and in severe cases lead to mortality. Solar radiation may also cause evaporation, thus increasing salinity in brackish environments. Evaporative cooling at night during the dry season, can reduce water temperatures considerably and may slow growth or stress the animals being cultured.

General Tidal Characteristics at Mariculture Sites

Tidal amplitude is important at the site because it can determine the pond bottom elevation, dike elevations, pumping costs, and the drainage pattern. The tidal frequency determines the pumping schedule, freshwater and saltwater mixing, and the drainage schedule. The tidal fluctuation or flux at the site may either be small or large and dynamic. A large tide would allow for good flushing action, whereas special arrangements may be necessary to discharge without a tide. In an area where tides are dynamic, the site should have minimal problems in relation to the removal of discharge water at low tide, but might experience problems at high tide. Another problem might come at low tide when there is no intake water. Accordingly, farms in many areas over-size the pump station to compensate for pumping at high tide only, and have very large reservoirs to supply water during low tide.

Water Quality

The quality of source water is an important issue in selecting sites for shrimp hatcheries and shrimp farms. Site evaluation should determine if the natural chemical and physical characteristics of the source water are adequate for shrimp. It also should reveal if there is a possibility of water pollution such as toxic or stressful concentrations of heavy metals, pesticides, other agrochemicals and industrial chemicals. Issues related to water quality in shrimp farming have already been discussed, and the reader is referred to Chapter 1 for this information.

Location	Temp. (°C)	Temp. (° F)	Salinity (ppt)	pH	DO (ppm)	NO3 (ppm)	NH3 (ppm)	PO4 (ppm)
Guanacaste	28	82.4	32	7.9	>6.0	0.45	0.67	13
North Punta	29	84.2	28	7.7				
South Punta	28	82.4	30	7.7				
Isla Negritos	28	82.4	30	8.1				
Rio Viscaya	26	78.8	10	7.6	6.0	0.50	0.31	0.25
Rio Estella	24	75.2	0	7.2				
Estero Negro	24	75.2	21	7.7				

Site Vegetation

The types of vegetation at the site usually vary according to elevation and soil type. A high density of vegetation equates to increased site development costs and should be avoided if possible. Mangrove or other swamps should be avoided.

Examples of Vegetation Indictors in Brackishwater Areas

Physical/Chemical	Vegetation Species Indicator
Elevated Areas	*Avicennia* (Mangrove)
Low lying Areas	*Rhizophora, Melaneura, Phoenix*
Clay soils	*Avicennia*
Sandy Soils	Nypa palm, grasses
Peaty Soils	Nypa Palm, *Melaneura*
Potentially Acidic	*Rhizophora*
Less Acidic	*Nypa, Rhizophora, Melaneura, Avicennia*

Avoid Nypa palm or other palms because they generally indicate a very sandy soil. If palms stand vertically this is usually an indication that there is some clay in the soil. If palms are leaning, this indicates there is more sand in the soil.

Soil and Soil Criteria Relevant to Site Selection

The physical factors of soils should be considered at the site. Will the soil type hold water? If not, the seepage can be a major problem. Seepage of water through soil can carry heavy metals. Metals can then influence the algae blooms in ponds and cause health problems in the cultured animals. The load bearing capacity of soils should be considered, as well as permeability.

The desired production methodology has a bearing on the type of soil that is acceptable. If liners are to be used, for example, as in the case of intensive systems, a sandier soil may be acceptable.

Soil type also affects the economics of construction and production (see Chapter 9). Certain soil types provide for economical dike construction and the larger the pond the less soil is moved to build the pond. Smaller ponds require more soil to be moved per unit of area impounded because of a higher ratio of dike area and generally greater water depth. Good soils help support primary productivity in a pond, and poor soils can work against primary productivity.

Soil texture is an important consideration at the site. Soil texture is one way to classify soils, and is determined by the size of the particles that make up the soil. Sand, clay or silt are the most common soil texture classifications and a combination is found most often in the field. Consult Hajek and Boyd (1994) for rating of soil types and water limitations in pond aquaculture.

According to Boyd and Bowman (1997) the best agricultural soils are loamy soils, comprised of a mixture of sand and clay and different size classes. A sandy soil will not retain much water and has a low capacity to adsorb and hold nutrients. A soil with a majority of clay-sized particles binds water and nutrients tightly, and is often sticky and difficult to till. A loamy soil is intermediate between the two extremes. A general rule for aquaculture ponds is that soils that are considered desirable for terrestrial agriculture, that occur in suitable locations for pond sites, and that contain enough clay to provide a barrier to seepage can be used (Boyd and Bowman 1997). Boyd (personal communication, 1999), states that the old myth that good soil must be 30-50% clay is not true. Soils with high clay contents are difficult to work with. A clay content of 10-20% is adequate for water retention provided the particle size distribution is suitable. Generally soils with a high sand content are to be avoided although there are exceptions. Beach sites with high percentages of sand are used successfully in Peru, although construction costs are increased because a greater amount of land is required, and thicker and larger dikes with less slope are required to avoid seepage. It is possible to import clay to use as the top layer of ponds and dikes, but construction costs are increased and are generally considered cost prohibitive.

The importance of physical properties of soil in design, engineering, and construction aspects of pond construction is obvious, but the chemical properties of soil that can influence shrimp production often are not considered in sufficient detail during site selection and construction. Soil quality had already been discussed, and the reader is referred to Chapter 1 for this information.

Hatchery Site Selection

The most important parameters to consider in hatchery site selection are water supply, water quality, availability of broodstock, fishing activity in the area, physical access, pollution, pesticides, flood and storm potential, prevalence of disease in the area, proximity to grow out ponds, culture methodology and degree of integration. Other factors to be evaluated included the potential for competition, amount of training required for local workforce, technical support in the area, availability of building materials, availability and cost of utilities, freshwater, and personnel comfort.

Hatcheries require a continuous supply of good quality water. Constant salinity through the year is ideal. The hatchery should be located within the narrow temperature range where the species of choice grows best. The turbidity should be less than 100 ppm to avoid expensive water treatment. It should be located in an area with low dissolved organics (less than 10 ppm) and no hydrocarbon pollution in the area. There should be no agricultural pesticides used in the immediate area.

A hatchery is best located where a high demand for postlarvae exists, whether it be from the grow-out component of the same vertically integrated operation or neighboring farms.

Biological Factors For Grow-out Facilities

The availability of healthy, wild postlarvae in the region for stocking ponds is a luxury. Studies to detect concentrations of shrimp postlarvae are recommended and will provide some information although populations and the presence of postlarvae are commonly highly variable. They may not always be available when needed. If production will depend at times upon hatchery-produced shrimp postlarvae, hatcheries in the area should be assessed.

Other biological factors should be evaluated. Is the ground covered with a well-established growth of plants, and if in a coastal area, are the plants salt resistant? Does the terrestrial animal community include a large variety of birds and insects? If absent, this may indicate a toxic problem. If the site is to grow fish or shrimp, are there healthy fish or shrimp growing in the area?

Many shrimp farms are located near estuaries and use estuarine waters as their principal water source. Estuaries are mixing zones for freshwater and seawater. The estuary contains minerals and organic matter that have been leached from the soils of its extensive watershed and carried by runoff to the coastal area. Benthic algae should be found in the resulting nutrient rich brackishwater, which provides the base for an extensive aquatic animal community. The faunal community may include a variety of fishes and crustaceans. Turbidity may be high in the estuary during the rainy season and may limit some of the aquatic growth. Oysters are commonly found in shrimp farming areas, but may not be there if there are toxins or if they have been over harvested. The appearance of plant and animal life in the area has several implications that are relevant. Carnivorous fishes are a direct threat to small fish or shrimp larvae if allowed to enter the ponds. Other fish could influence yields by competing for available food and by increasing the metabolic load and BOD in the ponds. The presence of other fauna is not necessarily negative and may be a sign of a high level of natural productivity and carrying capacity at the site. Indeed, this is why in a semi-intensive culture system (rather than a more intensive one) efforts are made to take advantage of natural productivity in estuarine waters. Under less natural condition (e.g. intensive culture) greater additions of fertilizer and higher quality feed would be required. The appearance of aquatic life, particularly postlarvae, juvenile shrimp and finfish, is an obvious indication that the physical and chemical characteristics of the water are well suited to the survival and growth of aquatic organisms.

Infrastructure

Road and/or water access to the site should be assessed. Materials and heavy equipment need to be transported to the site for construction purposes and normal operations. If roads or water access to the site do not exist, then they will have to be provided. Boats and barges should also be considered as viable methods of transportation to and from the site.

The power supply to the area should also be assessed. If a utility supply is not available, then generators can supply electric power until the utilities can be brought in from the nearest supplier. All pumps can be powered by diesel engines, although the cost of pumping will be greater than with electric motors. Electric motors powered by generators can be used to run the pumps. Generators can also be used for lighting, laboratory use and for domestic needs. Most utility suppliers charge for installing power (poles, wires, etc.), but in some cases they are provided as part of the service connection and everything within the site boundary is the responsibility of the owner. In some countries such as India and Nicaragua, the government generates and supplies the power at reduced rates. Arrangements must be made with proper authorities to ensure that an ample power supply can be provided once the expense of providing the infrastructure is completed. It may be more desirable to access the low cost government utilities and use generators for backup. Is 440 volt, 3-phase electrical power available? Although it can be more dangerous, this is generally more cost efficient with less energy loss in line transmittal. Natural gas-fired pumps are even more cost efficient than electrical pumps, and should be considered if the natural resource is available.

Is high quality aquaculture feed available? Are aquaculture feed mills available? Can the feed mill provide a constant supply of feed in quantities needed? If not, the extra costs of importing feed must be considered

Good telecommunications are a necessity at any aquaculture site. Ideally, telephone service should be available. A two-way radio may also provide additional communication particularly where telephone systems are not reliable. Cellular telephone systems are a good alternative where such services are available.

Other goods and services near the site should be assessed. The site should be relatively close to sources of building materials, equipment, heavy equipment and contractors. If these goods or services are not available, they will have to be obtained from elsewhere and may require importation. Procurement of supplies and equipment usually needs to be initiated well in advance, especially if they are imported and require customs clearance, payment of duties, and other paperwork. Timely processing of imports requires standardized systems and rigorous management. The existance of nearby hatcheries and processing plants should greatly assist in providing stock and in making marketing channel connections.

Social and Cultural Considerations

Success of an aquaculture business depends on the compatibility of the proposed operation with local communities and acceptance by residents. An aquaculture business is part of the surrounding community and being a good neighbor is important. Social considerations should be assessed from this perspective. The villages and communities near the site should be investigated and their conditions taken into account. Potential socioeconomic impacts, both beneficial and negative must be identified and carefully weighed when selecting a site. There are multiple examples of aquaculture projects that held promise of being economically successful, but were halted due to concerns of local residents. In many cases, this has resulted from lack of consideration and acknowledgment of local concerns.

A knowledge of the current uses of the site and surrounding areas is key, since proposing a project that disrupts traditional land use, affects natural resources such as fisheries, or interferes with other activities is bound to encounter difficulties. If resource use conflicts exists, or if the livelihood and traditional use of others is affected, careful negotiation and possible compensation is recommended regardless of the legal status of the land or legal obligation to consider compensation if the operation is to succeed.

Aquaculture can offer many benefits to local communities, the foremost being employment opportunities. Where possible, local residents should be given priority in hiring as this helps foster a good relationship with the community and establishes a stable source of labor. Wherever possible, trainees for technical positions should also be drawn from surrounding areas.

Security is an issue at aquaculture operations. A policy of promoting a good relationship with the community can often be the most effective means of maintaining security at the site. A security fence is usually a requirement to protect the crop from poaching and theft, although care should be taken not to disrupt the normal routine or travel routes of villagers. Hiring security personnel that are not from local communities may be considered as an exception to the general rule of hiring local residents.

The labor profile in the area selected should be obtained. It is generally a compromise between skilled and unskilled workers, and skilled labor must often be brought in. Consideration should be given to local customs and traditions, as well as local labor laws. In Panama and other Central American countries, the wages of a "13th month" and several weeks of vacation are given at the end of the year to employees, and this must be budgeted into the project.

Potential housing for employees should also be assessed. Some of the technical staff must be available round the clock at the production site and should be housed on-site. To attract the highly skilled staff required for the site's development and management, it is important that pleasant living conditions be made available. The majority, however, will live off the site. A more detailed look into the social dimensions of aquaculture development was undertaken by Bailey, Jentoft and Sinclair (1996) and is recommended reading.

Other Important Considerations

When conducting the site survey keep in mind that no site is perfect, no two sites are the same, and that the survey should assess both technical and non-technical parameters. It should include agricultural and economic data. An expert who has selected other suitable sites and has followed up on the results should conduct the site assessment or survey. An inexperienced person should not be in charge of site selection. The site assessor should utilize as much local assistance, extension services and experience as possible, and only rely on data that is documented and reputable.

Site Survey Equipment

Site survey equipment might include a shovel, hand-held auger or backhoe for taking soil samples, soil and water pH meters, hand-held salinometer/ refractometer, or a portable water test kit. Other equipment might include radios, compass, plastic or glass water sample bottles, plastic soil sample bags, binoculars, camera, maps, insect repellant, drinking water and other personal items. If soil samples are collected outside the U.S. and shipped to the U.S. for analyses, they must be mailed or sent via courier service such as DHL, Airborne, or Federal Express. The United States Department of Agriculture (USDA) will not allow the personal transport of soils into the U.S. A permit from the soil analysis laboratory is required and must be placed with the shipment. This permit ensures USDA that the imported soil will be disposed of properly after it is analyzed.

Availability of Construction Equipment and Materials

Heavy equipment is not always available or commonly used in an area. Imported equipment will add to the cost of the construction. The load bearing capacity of the soil at the site must also be taken into consideration. This will determine the type of equipment that can be used. If low-lying areas are to be developed a dragline, Hymac or other special equipment may be needed. A dragline can build a road or dike in front of itself by removing soil on either side. Hymacs can knock brush or trees over and use them for a base while excavating. The availability of cheap raw materials will influence construction costs. The price of sand, for example, can make a big difference in the cost of a hatchery.

Other Land and Topographical Criteria to Consider

The distance of the site from the water source can make a big difference in cost and selection of pumps and piping. The slope toward the ocean or other drainage area should be considered. For best results the area should have a minimum slope or drop of 2/1000 (for every 1000 units traveled horizontally, the elevation drops 2 units). Undulations will require fill or excavation and will add costs to construction. The location of ground water is important and will determine whether the site has sufficient elevation for proper pond drainage. A minimum of 30 cm (1 foot) is needed between the lowest part of the pond and the water table.

Quick Method For Evaluating A Site

A quick method to objectively evaluate a site is a weighted ranking system. In this system, site selection criterion are developed and a relative weight of importance is assigned to each criterion. The relative weight of each criterion ranges from 1 to 3 with 3 being the most important and 1 being the least important. Then the site is evaluated for each criterion and scored from 1-5, with 5 being optimal and 1 being poor. Multiply your score by the weight to obtain the weighted score. Add the weighted scores and compare to the totaled ideal scores to obtain an objective evaluation (see the following table for an example).

Example of a weighted ranking system

Criterion	Your Score	x	Weight	=	Weighted Score	Vs	Ideal
Soil Quality	3	x		=	9		15
Water Quality	3	x		=	9		15
Socio/Economic	4	x		=	12		15
Topography	5	x		=	10		10
Elevation	5	x		=	10		10
Available Area	5	x		=	10		10
Potential Flood	2	x		=	4		10
Ownership	5	x		=	10		10
Accessibility	5	x		=	5		5
Vegetation	4	x		=	4		5
Mechanization	3	x		=	3		5

Site Evaluation and Scoring

In this example of a rapid site evaluation, a score of 86 was obtained and thus the location was considered to be an excellent site. Caution should be taken to further investigate a site after this rapid appraisal.

Range of Scores (%)	Evaluation
100-80	Excellent Site
79-60	Good to Fair
59-40	Marginal
<40	Avoid Site

Engineering Survey

Once a site is selected, it is necessary to gain a more detailed knowledge of the site in order to finalize the precise elevation and positioning of the ponds, water supply and drainage systems. A detailed study should include the site's shape, the topography, the relationship to the surface water source or estuary (if applicable), the lateral profiles, the natural drainage, and the future locations of structures such as supply canals, dikes, drainage and infrastructure. An engineering survey is generally required to plan the project adequately. Physical references and benchmarks should be established that correspond to plotted positions on the site plans. Surveying the chosen site is a must because the engineering will require exact distances, directions and other detailed knowledge of the area.

See the following references for additional information on aquaculture site selection: Avault (1996), Webber (1972) and Welborn (1990).

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3

POND DESIGN AND CONSTRUCTION

POND DESIGN AND CONSTRUCTION

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POND LAYOUT CONSIDERATIONS

Good pond design and construction are key to efficient functioning of the farm and the costs of construction and management. A well-designed and properly constructed operation also makes controlling potential environmental impacts easier.

Wind

Wind has three major effects on water in culture ponds:

(i) it circulates the water, thus mixing the layers of differing density which tend to form in ponds (stratification);

(ii) it tends to lower the water temperature by increasing evaporative cooling; and

(iii) it generates waves in a pond which can cause erosion of pond banks.

The potential of the waves to cause damage is proportional to the velocity of the wind and the distance of the fetch [1]. The larger the pond, the higher the probability of damage from erosion.

Prevailing wind direction and velocity exhibit a distinct, seasonal variation. Seasonal data on wind direction and velocity should be collected before the design phase. As a general rule of thumb, wind will blow from the direction of a major body of water (ocean, bay, etc.). The length or longer axis of the rectangular ponds should be orientated perpendicular to the wind (Figure 1). Thus, the strongest and most persistent winds will blow across the shortest axis (width) rather than down the longest axis (length) of the ponds. This will minimize the wave generation the resulting erosion.

1 Fetch = the distance that wind travels across a pond.

Orienting a pond so that it is perpendicular to wind direction will thus generally result in ponds that are aligned with the long side parallel to the beach or other water source. This often places the ideal pond alignment contrary to the property lines, highways and other existing structures. In these cases, some compromises may have to be made in pond design.

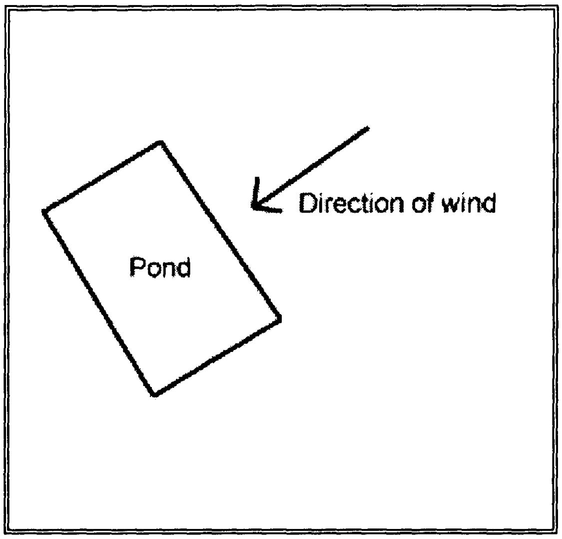

Figure 1. Ponds should be oriented so that the long axis of the pond is perpendicular to the prevailing wind.

Rectangular ponds are the most common pond shape because this maximizes the benefits of water of water exchange in a semi-intensive culture pond since water enters on one side and drains from the other. Circular ponds have very good water circulation characteristics, but poorly utilize available space. Although use of a square pond would minimize erosion, these are rarely used except in intensive culture systems because they have circulation problems reducing the benefits of water exchange.

If hurricanes and/or cyclones occur in the area, special procedures should be followed to protect the ponds during the storm. Precautionary procedures include lowering pond water level before the storm hits to prevent the pond from overfilling and causing a dike collapse. This requires being able to rapidly drain ponds. Peripheral dikes can offer additional protection if their maximum height is above that of the 100-year flood level.

Rainfall

Rainfall affects shrimp farming in several ways:

(i) it dilutes pond water, thus lowering salinity;

(ii) it causes erosion to the pond banks, roads, and other earthworks;

(iii) it promotes the growth of erosion preventative grasses on the pond dikes; and

(iv) it lowers water temperatures.

In the tropics, rains are intense and seasonal which both benefits and threatens ponds. Heavy rains may damage dikes and roads during the rainy season, while long periods of dry weather discourages the growth of protective vegetation. On the other hand, the monsoon rains usually tend to lower pond water temperatures during the hottest time of the year when they need to be somewhat lower.

Farm roads should be coated with rock or some other economical surface to make an all-weather road to provide continuous access to all ponds.

Pond Depth Considerations

The warm climate in shrimp farming areas is well suited for the operation of shrimp farming throughout most of the year. The high temperatures and light winds during the dry months may elevate water temperatures in the ponds above the optimum levels (greater than 31 °C); therefore, the ponds should be designed for an average water depth of 1 to 1.2 meters. The deeper ponds will provide a thermal reservoir, which will help to buffer the ponds against annual and diurnal temperature fluctuations.

Similarly, a larger volume of water in a pond will act as a reservoir with water of suitable salinity, helping to prevent drastic changes in salinity during heavy rains or prolonged periods of drought.

As a further protection against wave and rainwater erosion, the banks should be stabilized by compaction of selected soil during construction, planting stabilizing vegetation or encouraging the natural re-occurrence of vegetation.

According to Boyd (1999) an average depth of 80-100 cm is adequate in semi-intensive ponds, but with intensive ponds, an average depth of 150 to 200 cm is preferable.

Water Resource Considerations for ponds

The tidal range should be considered in deciding upon locations for ponds (Figures 2 and 3). Tides in excess of 5 feet above mean sea level may occur. Areas with a tide of 3 feet or just under one meter will have good flushing action and artesanial ponds without pumps must be built in this range. If ponds are too low to drain properly at high tide then pumping may be necessary to drain ponds. Ponds built above the high tide mark cannot be filled by tidal action; this may not be a critical impediment in most cases since most ponds are now filled by pumps as is recommended.

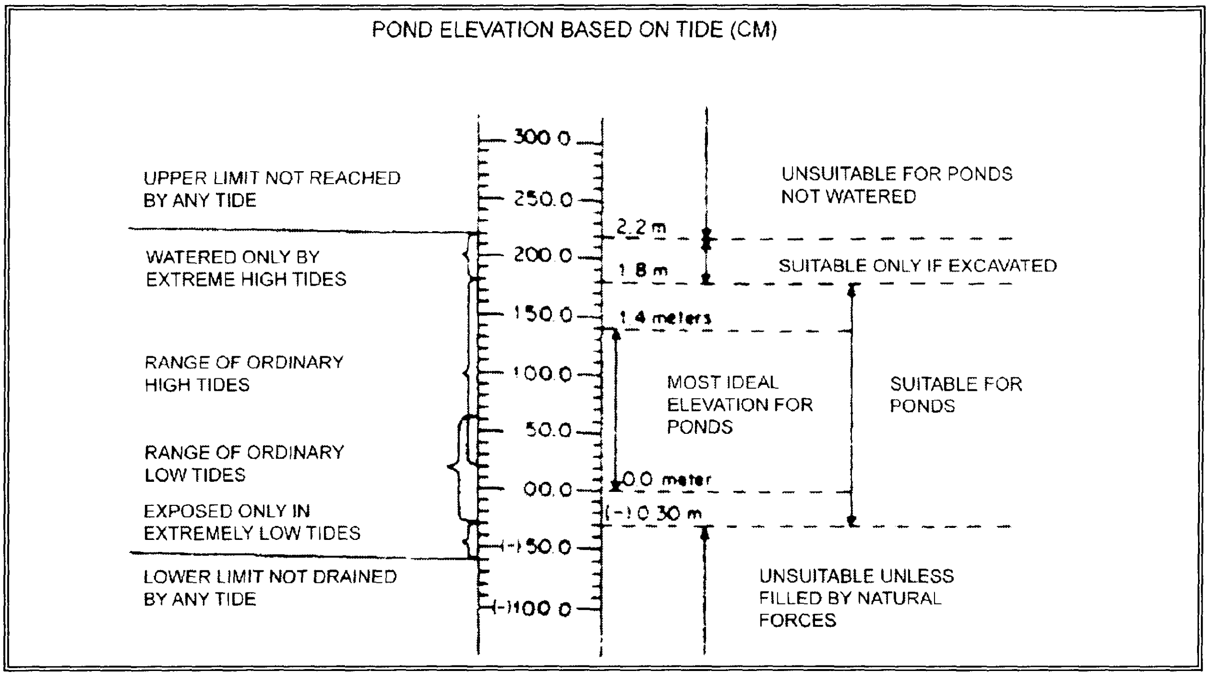

Figure 2. Suitability of proposed pond site based on tidal range and elevation under Philippines conditions with tidal range of -0.6 to 2.2 m FAO (1983).

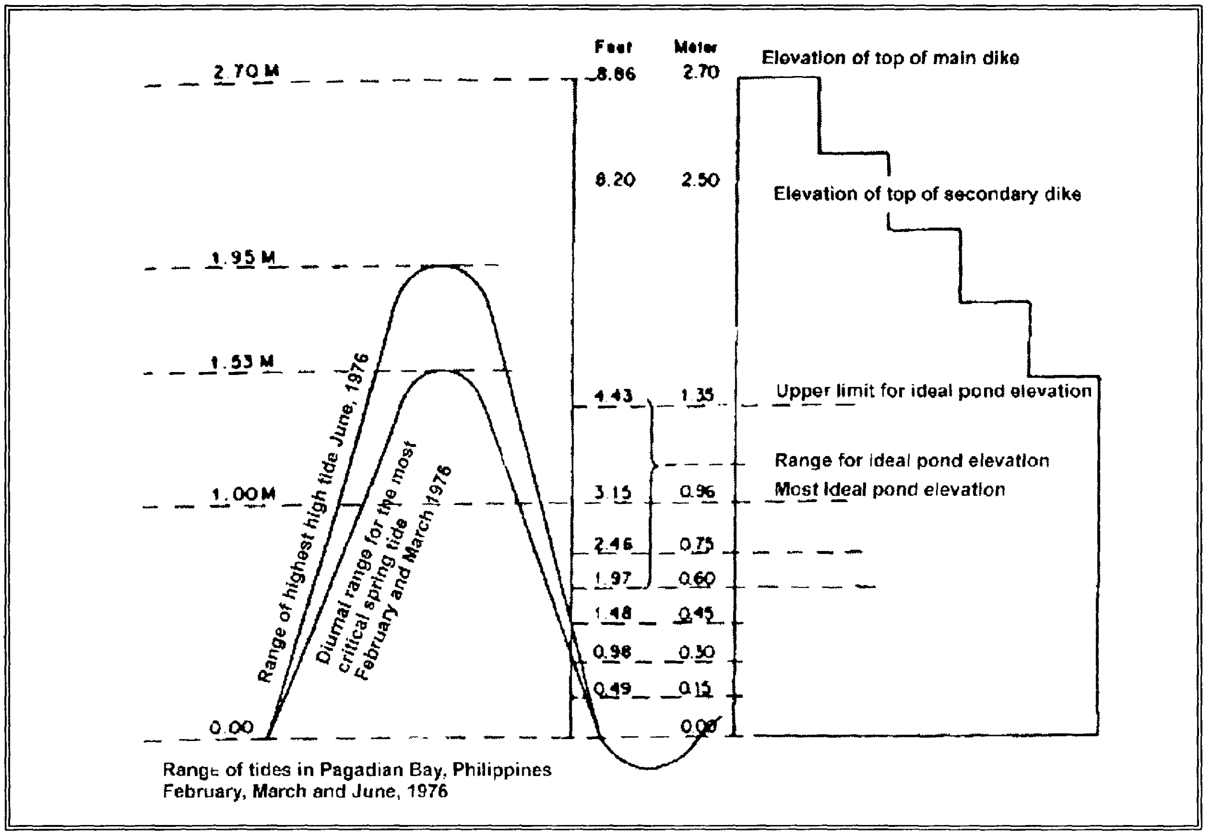

Figure 3. Relation of tide curves to different pond elevations FAO (1983).

Configuration and Alignment

The farm configuration should be designed to ensure the most cost-effective use of the site topography. Water is pumped from the source to an elevated supply canal. The elevated canal serves to supply water to ponds by way of gravity flow. Water supply gates connected to the supply canal supply the ponds with brackishwater. On each side of the main water inlet gate of a pond there should be additional water inlets to insure proper water circulation in the pond. The secondary inlets can be made of PVC pipes with standpipes in the reservoir or supply canal with screened inlets and movable 90-degree elbows which allow the standpipe to be lowered into the reservoir when water is needed. The supply canal also acts as a settling reservoir to settle out solids pumped in from the water source. Suspended solids may cause problems in the rainy season when run-off occurs and suspended materials are in a river or a tidal source of water. A rule of thumb concerning multiple inlets is if a pond is wider than 180 meters, it is recommended that multiple inlets be installed. The end or outside inlets should be located at least 10 meters or more in from the corner of the pond.

INFRASTRUCTURE

Road and Water Access to Ponds

The farm site should have a well-constructed, well-maintained road that connects it to the nearest city. Materials and heavy equipment must be transported to the ponds for construction purposes and deliveries made with no problems. Many farms can also be accessed by water and inexpensive transportation is the key here. Workers must be able to get to the shrimp ponds to feed or to harvest in any type weather.

Power Supply to Ponds

Pumping can be powered in three manners: electric engines directly powered by an external electric source, electric motors powered by a diesel generator or the pumps can be diesel. Electric power should be supplied with a stand-by generator for emergencies. Arrangements will need to be made with proper authorities to insure that an ample power supply can be provided once the infrastructure is completed. Depending upon the power source and cost, it is usually more desirable to utilize private or government utilities, and use the company's own generators as back up, than the reverse. Sometimes it is less expensive if the company produces all of its power needs. If natural gas is available, pumps can be operated much less expensively using this source of power. Aeration may present another need for power. Installation of aerators would also require that proper electrical connections be made on the pond banks to supply power to the aerators.

Goods and Services

The pond site should be relatively close to sources of building materials, equipment and contractors. Heavy equipment should be available and the area should have suppliers and contractors. Heavy equipment should be available and the area should have suppliers and contractors of the competency and experience required for the scope of work. If the goods or services are not available, these will have to be obtained from elsewhere and some may require importation. Procurement of supplies and equipment may need to be initiated well in advance.

OTHER POND DESIGN CRITERIA

Shrimp Culture Strategy

The basis of good pond management is a farm structure that lends itself to efficient operation and takes into consideration the needs of the shrimp. Traditional shrimp farming evolved with little or no application of engineering principles. Tidal estuaries, where shrimp were trapped or netted, became ponds by excavating the bottoms and building-up dikes around these naturally flooded areas. Existing channels that fed and drained these areas were fitted with simple wooden gates for more control of tidal water. However, these improvements did not consider the requirements of the impounded shrimp and production in these artesanial ponds was low. Even as shrimp technology advanced and intensified, engineering principles were still not consistently applied to construction, water supply or logistic support designs with the result that many ponds even today are built so poorly built that production is adversely affected by construction flaws.

Our knowledge of *Litopenaeus vannamei, L. stylirostris* and other penaeid species has improved significantly since shrimp culture began. The effects of specific site conditions on farm construction and operating costs and efficiency are well known. A list of design criteria can be developed based on these two areas of knowledge.

The following discussion considers requirements of shrimp and actions taken during pond management that have a bearing on farm design and construction.

Intensity of Culture in Ponds

In Latin America, semi-intensive culture has been considered the most appropriate since it make comparatively efficient use of space while not requiring high levels of inputs such as aeration. For the purposes of discussion let us consider the example of a hypothetical farm designed to yield an average of two crops per year, with an average weight of 18 grams per shrimp for *L. vannamei*, and 24-28 grams for *L. stylirostris* in semi-intensive culture. This farm will employ larger (20-acre) ponds. Additionally, this farm has a recirculation canal that allows for reuse of water or can act as a settling basin before final discharge into the receiving water.

Water Exchange in Ponds

The pond water intake system will be designed so that during routine operations, every pond can receive a minimum exchange of water per day (3-10% for semi-intensive culture ponds). Realistically, almost no water is used the first month, and then only a 3% exchange is needed to culture at the densities planned for semi-intensive operations.

The most effective way of exchanging water is to first drain the desired amount of the water from the pond bottom. This effectively removes the poorest quality water and detritus which accumulates at the bottom of the pond. This process is assisted by constructing weir gates in the discharge structure so that water is removed from the bottom by the removal of board slats on the bottom of the front row of boards, allowing water from the bottom to escape over the top of the second row of board slates (Figure 4).

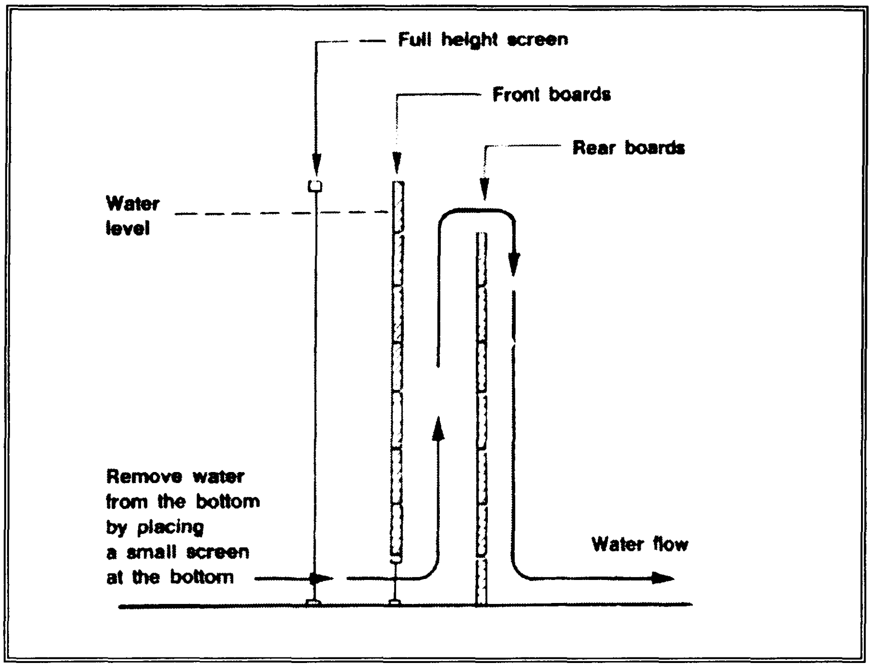

Figure 4. Side view of a drain structure demonstrating correct placement of screens and the use of slatted, wooden boards to control the level at which to be drained.

Refilling of each pond is done during the rest of the day. The pumping system should be designed with a storage reservoir or settling reservoir and from there, the gates must be designed so that water flows by gravity to the ponds; therefore, draining all ponds in the morning and running the pumps to refill the reservoir in the afternoon or at high tide is one way to efficiently operate the ponds. Recirculation should be used, therefore only 652 million gallons of water per year will be required to operate twenty, 20-acre ponds. This is based on an estimation of 300 gallons of water required for every pound of shrimp produced. This water is mainly for filling the ponds and to offset what evaporates from the ponds. Other water will be recirculated.

For extreme conditions, the pumping, intake and drainage structures capacities of the ponds should permit a 33-50% water exchange in any one pond over a 24-hour period. This will ensure that, even under the worst conceivable condition of poor water quality and/or oxygen depletion, there would be little risk of major stock mortality.

Pond Drainage

The main drainage for pond effluents should be as far away from the intake as possible. Having water inlets and drains on opposite sides of a pond maximizes water exchange.

Design and layout also should take into account procedures for reducing negative environmental impacts of pond effluents and are discussed in chapter and Chapter 10.

Canal Structures

A general rule of thumb is that the sides to all structures should have at least a 1.5 to 1 (horizontal to vertical) slope (Figure 5). A good construction engineer familiar with soils can determine if this is adequate for good slope stability and erosion control under given circumstances. For example, a silty loam can generally support above grade earthen embankments with steeper than 2.5 to 1 slopes. A less steep slope might be desirable, but this would require more space and entail higher construction costs. Steeper slopes require less soil to construct and entail lower construction costs. Steeper slopes require a higher clay content; therefore, a 2 to 1, a 1.5 to 1 or even a 1 to 1 slope may be possible where clay content is sufficiently high. In most cases, a 2.5 to 1 slope would be recommended for a typical canal slope.

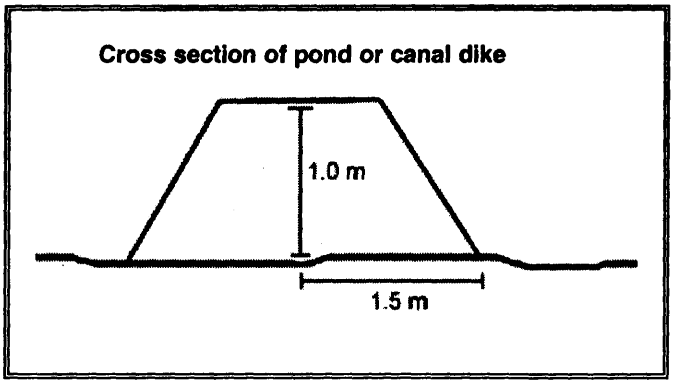

Figure 5. Cross section of a pond or canal dike showing the ratios of the 1.5: 1 slope of the sides of the dike.

Farm Pond Roads

Access roads will facilitate feed distribution to the ponds and other important tasks such as transporting product out as quickly as possible after harvest. If possible main roads should have a 4-5 m wide crown and an elevation equal or greater than the pond dikes. The sides should have a minimum slope of 2:1. The main road into the farm must be able to support heavy equipment and trucks with product (feed coming in and shrimp going out) on a year-round basis. The rainy season is usually the most difficult period to negotiate the road and is when the most damage to the road and farm dikes occurs. If river silt soils are present on a farm, roads will need to be re-surfaced frequently.

Growout Ponds

The growout ponds are generally rectangular in shape. A pond size of 8 ha (20-acre) lends itself to semi-intensive culture management, and maximum utilization of the site topography. The initial cost is lower to build an 8 ha pond in comparison to a smaller pond because more earthwork is required to build the smaller pond with more levees. With larger ponds, water requirements are generally more difficult to meet, but if water recirculation techniques are used and sufficient pumping capabilities are built into the design of the pumping station, water requirements can be satisfied.

A cross section of a grow-out pond, supply canal and adjacent road are shown in Figure 5. This figure illustrates the spatial relationship of the various earthworks with respect to each other.

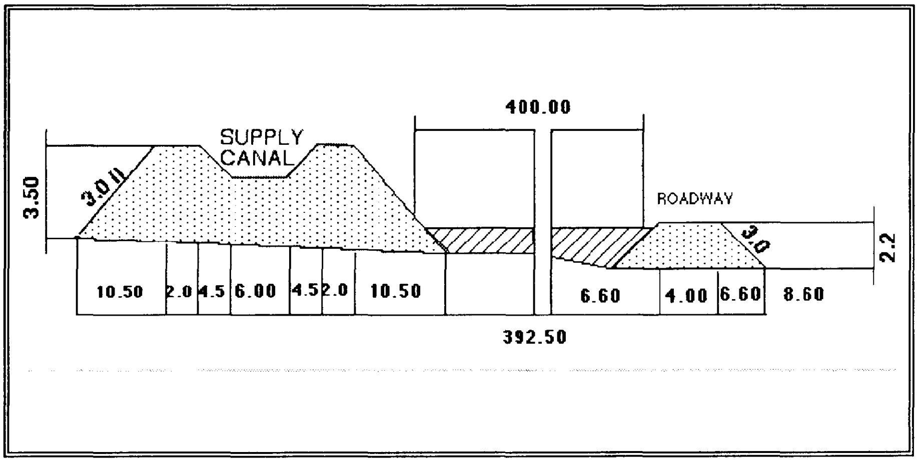

Figure 5. Relative elevations and proportions of supply canal, grow-out pond and road.

Ponds should have an average water depth average of 1 m to 1.2 m. The deep end may even be 1.7 to 2 meters deep in some cases. When the ponds are filled, they will be fertilized to encourage the growth of phytoplankton. These plants, by virtue of their density, provide shade. With a depth of at least one meter, a normal phytoplankton bloom will block light penetration to the pond bottom thereby eliminating undesirable proliferation of benthic (bottom-dwelling) filamentous vegetation. Also, shrimp prefer areas with low light intensity and will probably spend more time in the deep end of the pond during daylight hours or will burrow in the sediment and emerge at night.

On hot, still days, a thermocline (lower density warm water stratified over higher density cooler water) will develop within the pond. The upper layer will absorb most of the sun's solar radiation. Since thermal conductivity across the thermocline is relatively low, the bottom of the ponds will remain cooler. In this way, a good phytoplankton cover in conjunction with the proper water depth, will provide effective shading and cooling.

In designing a pond, it is important to insure that there is sufficient space between the tops of the dikes and maximum water level (freeboard). The required amount of freeboard depends on the maximum expected height of waves, which in turn is dependent upon the fetch and wind velocity. A general rule of thumb is that a freeboard of 1.5 feet will prevent water from splashing onto roads and access dikes on windy days and thus ensure a longer life for these structures. However, local wind conditions and the size of the pond will determine the actual freeboard required for adequate protection.

Pond bottoms should slope toward the outlet with a gradient of at least 1:1,000 (i.e. pond bottom elevation drops 1 unit for every 1000 units of pond length). The drainage canals will be on the opposite side of the pond from the intake or supply canal to insure the maximum benefit of water exchange. Drainage in ponds should be designed to be possible even at high tide. If this is not possible, then a dike with a one-way gate can be constructed and discharge pumps can drain the discharge canal even at high tide. This is an added expense that should be avoided if possible.

Soils are covered in other sections of this manual. If the soil does not have sufficient clay and silt to keep water from moving in either direction through pond walls, then an impermeable barrier such as a PVC liner must be placed in the dike. PVC liners are cost prohibitive in some countries so choosing a site with proper soil composition is important.

Perimeter Dikes

The highest recorded flood level in the area should be transferred to the site from a benchmark reference. By adding a minimum freeboard of 1.5 feet, the desired height of the perimeter dike can be determined. Perimeter dike is optional, but should be built to protect the farm from the highest recorded tidal surge.

Internal Dikes of Ponds

The height of the intermediate dikes of ponds will vary (usually at least 1.5 to 2.0 m high), and can be determined from information from a contour map and recommendations from a qualified engineer. There should be a 50-cm (approximately 2 feet) freeboard. The crowns are designed to carry only light traffic and should be a minimum of 2-3 m wide. The slope of the dike walls is determined by the soil texture, and both the sides and the crowns should be planted with a salt-tolerant grass to minimize erosion. In a sandy area slopes of 3:1 (up to 7:1 in some areas) may be necessary, but the greater this slope, the more costs will be involved to move more earth. For example, ponds on a sandy beach in Tumbes, Peru commonly have a 7:1 slope. Those ponds are built parallel with the beach and are long and narrow rectangular ponds.

Inlet Canal and Supply Canal to Ponds

If an inlet or intake canal is used to supply water to ponds, it would generally run perpendicular to the water source. The supply canal water level must be at least 20 cm (8 inches) above the highest level of water in the pond to get good water movement into the pond. There should be a minimum of 30 cm of freeboard ranging up to 70 cm of freeboard in the pond, depending on conditions. For a 600 acre farm for example, the canal should be approximately as long as the farm is wide, and should be a minimum of 10 m (370 inches = 30 feet) wide by at least 2m deep to insure that pumps do not suck the canal dry. The dikes will vary from 2.2 to 2.8 m high or higher depending upon the contours of the land. Measures can be taken to promote settling of suspended solids within the canal by designing a baffle system if solids become a problem in the rainy season. The canal baffle system will need to be cleaned occasionally depending upon the suspended solids encountered. Pumping at high tide will lessen silting usually.

Inlet and Supply canals in relation to Pump Station and Intake Pumps

The pump station is generally located at the water source unless wells are used. The pump station can be all electric, diesel or natural gas and should be fenced for security. Pumps lift water at high tide from the source and discharge it directly into an open canal. This is the least expensive method to move water. If necessary, PVC pipe can be used to carry water to the ponds. The water can either enter directly into ponds with individual concrete gates and board slates to control inflow at each pond or it can be piped with individual gate valves at each inlet. It is generally best to pump water into an elevated supply canal, filtering once at that point, and then filtering again at the pond inlets. The supply canal acts as a reservoir and settling canal to settle solids. This canal will have a tendency to accumulate silt and special efforts and operating funds will be necessary to maintain it. This elevated supply canal can in turn be split into multiple supply canals to serve various sections of the farm. Discharge would be out the opposite end of each pond into discharge canal(s).

Most pump stations have multiple pump positions. For a 400-acre farm, for example, the pump station should accommodate enough axial flow pumps to provide 1.8 million gallons per day through 15 foot in height (Total Dynamic Head-TDH). Thus the designed exchange rate for the growout ponds is 3-10% in each per day, including the water recirculation pumps, which are separate from the intake pumps at the water source.

Water should be available at any time. This is achieved through placing pump intakes at the bottom of the water source and with the minimal tidal fluctuation (1.5 to 3 feet), it is expected that pumping will always be possible. If the supply canal is elevated or the PVC supply pipes are placed above the pond water level, flow of water to the pond will be always be possible in this phase. Check with pump suppliers (i.e. Lippert International or Caterpillar, Miami, Fla., etc.) for information on pump size and costs and suggestions for pump station designs. Pump suppliers should assume some responsibility or provide a warranty for their pumps. Always use modern efficient pumps. The larger diameter pumps will operate more efficiently with larger volumes of water, but the depth of the pump station would need to be assessed. A series of smaller pumps may be necessary or more desirable. It is an absolute necessity to always have a backup pump. Use concrete to fortify the base and sides of pump stations to prevent erosion.

Intake Canal and Supply Canal Requirements

The elevated supply canal will supply the ponds on the farm and is controlled by gates at the canal inlet, outlet and pond inlet. Rapid water movement should not be seen in the intake canal if it is designed properly and it should be designed accordingly so that suspended solids will settle. The general rule of thumb is that a velocity slower than 0.3m/sec will promote siltation or settling, and velocity faster than 0.7m/sec will cause erosion.

Periodically, the supply canal may need to be treated with chemicals to eradicate predator and competitor species that have become established. The ability to lower the water level will reduce the amount of chemical required for this task. Often silt can be removed from the baffle area in the supply canal at the same time chemicals are applied.

Pond Inlet Structures and Flumes

Inlet structures for discharge of water into the ponds are built into the sides of the supply canal. The inlet gates for the growout ponds should be sized to accommodate a maximum gravity flow of 33% of the pond volume per day, which will be adequate for filling and flushing. The inlets are designed for continuous flow from the supply canal to the pond at a constant flow rate and can be adjusted for head differences between the ponds and the supply canal. Care must be taken when the ponds are first filled to be sure the gates are sealed, and do not leak. The soil around the gates must be packed well. If a leak is detected around a gate, immediate attention must be given to prevent a blowout. A 3,000-pound concrete gate structure will move if a pond dike blow out occurs.

Fine screens should be inserted into the gates to prevent the entrance of predator and competitor species into the ponds. Coarse screens, designed to minimize clogging and the restriction of flow during maximum flow conditions, should be positioned before the fine screens. The pond banks below the inlet structures can be protected from erosion by riprapped channels or cement if erosion is a problem.

Pond Outlet and Harvest Structures

The outlet gates in the growout ponds should be sized for draining at a rate of 5% per hour. The gates will be screened to prevent shrimp from escaping during water exchange and to prevent predators from entering the ponds from the outlet. They should be designed for efficient drain harvesting and the transfer of shrimp to processing. The outlet should slope down 30 cm and there is usually a step down of another 30 cm into the harvest chamber to ensure complete drainage of the ponds.

The level of the estuary should always be lower than that of the pond bottom during and after the rainy season. Otherwise, pumps will be needed for harvesting, draining and drying the ponds. The harvest chambers of the growout ponds are usually designed with gates, even if pipes are selected to be used alone for the inlets. The outlet/harvest gates should be constructed of concrete or some durable material, and any drain pipe used should be 18 inches or larger in diameter so that shrimp will not feel the back-pressure at harvest and attempt to avoid the drain. A 36 inch diameter pipe is commonly used for drainage into a harvest pit or basin. If an automated harvest system is desired, then a one-meter deep sump can be included in the floor slab of the harvest chamber to accommodate a dewatering-harvest pump.

Harvesting and Drainage

During and after the heavy rain periods, harvested ponds should be dewatered by gravity drainage. The use of mobile centripetal or axial-flow pumps should not be necessary for harvesting or drainage if the elevations of the ponds are set properly by the engineer. If it is found to be necessary, the required pump capacity is 9,700 gallons per minute at 11 foot TDH for draining a 20 acre pond. This task could be achieved by two 40 HP pumps. One pump could be operated at a time and the other pump could be kept as a spare.

Automated harvest systems (for e.g. Magic Valley Heliarc) offer an improved method of harvest that, when working properly, provides an excellent way to get the product out of the pond and on ice immediately. The product is generally superior, clean, and untouched by human hands. Most automated harvesters are capable of harvesting a minimum of 3,600 lbs of shrimp per hour.

Office/Control Center and Other Buildings

To maximize the pond water surface area, only those buildings that are required to be situated on the main site should be included. All buildings should to be positioned for easy access and for security of the ponds. The office and control center should be positioned close to the main entrance of the farm. Guard positions should be sited near the edge of the farm, at the main gate near the main road and at the intake canal/effluent canal. An open-sided building or cover can be used for feed storage or as a shop. There is usually a house or office/laboratory with an electrical supply back-up generator and combination office/guard tower. Sometimes housing is provided. A few guard towers for security guards should be constructed on the pond banks at vantage-points or corners of the property. This will ensure close observation and management of the ponds and better security. Sheds at the pump station will provide protection from the elements for the pumps.

Roads to Ponds

The access road and the perimeter dike, which joins the access road to the central storage and office area, should be 5 m wide. The road around the rest of the perimeter dike, along the side of the central area can be 4 m wide. The all-weather surface of these roads is for heavy traffic and should be finished with a rock base (called laterite in some places) or other appropriate material, and connect to the main road that would take the product to the processing plant.

Pond Construction Suggestions

Prior to pond construction, a detailed site survey should be conducted to determine precise engineering details.

To finalize the precise elevation and positioning of the ponds, water supply and drainage systems, it is necessary to have a more detailed knowledge of the site's shape, topography, relationship to the water source, lateral profiles, natural drainage, plus planned structures such as inlet canal, supply canal, dikes, drainage and infrastructure. Physical references and benchmarks need to be established that correspond to plotted positions on the site plans. A survey should be carried out and a contour map of the site should be prepared if it does not already exist. Markers of corners and boundaries should be permanently established.

The annual rainy season should be considered when scheduling pond construction. Heavy equipment may be rendered useless with the rains. Based on these assumptions, an annual construction season of only 6-9 months should be expected in most areas. In addition, the section of the facility that is completed during the dry season should be protected by either temporary or permanent dikes before the rains start.

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SHRIMP NUTRITION AND FEED MANAGEMENT

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General Shrimp Nutrition

Throughout their life cycle, shrimp exhibit various modes of feeding. As young larvae (zoea), they are planktivorous, filtering microscopic algae and other suspended materials out of the water. As older larvae (mysis) they are primarily predators consuming largely animal protein sources (e.g. *Artemia*). As they metamorphose into postlarvae and finally into juveniles they become benthic scavengers and derive their nutrition from a variety of food items (*omnivorous*).

The growth and survival of shrimp in the wild depends upon various factors including adequate water quality, a supply of natural food and protective habitat.

The objective of shrimp aquaculture is to provide adequate water quality, habitat and nutrition for rapid growth, but at biomass densities much higher than those found in natural waters. In other words, the role of the shrimp farmer is to remove the uncertainty and inefficiency of nature.

Nutrient Essentiality

Shrimp nutrition is a complex subject because the nutritional requirements of shrimp change with the stage of the life cycle. Thus, shrimp feeds must be specifically formulated for different states of the life cycle. Moreover, natural food items supplement manufactured feed, and shrimp farms should manage pond ecosystems and feed inputs to maximize the benefits of both natural food and manufactured food.

Although the nutrient source may vary, certain nutrients are required by all growing animals. These are known as *essential* or *indispensable* nutrients. An essential nutrient is one that cannot be synthesized by an animal at the level required for normal growth and maintenance. Although protein is required for growth, there are no essential proteins. Instead, there are essential *amino acids* (proteins are composed of amino acids). Although feed carbohydrates (e.g., wheat flour) are considered suitable energy sources, there are no essential carbohydrates. Carbohydrates can be derived from various feed ingredients, stored and released via several metabolic processes. In addition dietary lipids and lipid stores can serve as energy sources. Finally, there are essential fatty acids (components of lipids), vitamins and minerals.

Nutrient essentiality can be further differentiated in quantitative terms. Nutrients such as proteins, lipids and carbohydrates are often referred to as *macronutrients*. Their presence in feeds comprises a substantial portion of the space available or weight of the diet. *Micronutrients* (e.g., minerals and vitamins), on the other hand, are those required by shrimp in relatively smaller amounts. The term *"micro"*, however, should not be interpreted as implying that such nutrients are less important to the nutrition of growing shrimp. Some vitamins are required in very low concentration in commercial production feeds (e.g., ascorbic acid, at around 100 mg/kg dry feed) but their inclusion is absolutely required for proper growth and maintenance. In other words, reduction of any essential nutrient from a production feed, no matter how low the requirement, could result in not only restricted growth, but also substantial mortality. In estimating whether essential nutrients have been included at adequate levels in feeds, it is important to identify all potential sources of nutrition and associative availability.

The term, nutrient *requirement level*, is often confused with that of nutrient *feed level*. If an essential nutrient "x" is determined under controlled conditions to be required by shrimp as 3% of the diet, it may not equate to a feed inclusion level of 3%. Providing a specific requirement level of a nutrient is sometimes difficult in feeds due to losses associated with the manufacturing process (e.g., high heat) or variations in digestibility associated with different nutrient sources (feed ingredients). In other words, what is formulated is not what will be in the feed, once it has been processed. In addition, research diets used to estimate nutrient requirement levels are often prepared with highly digestible feed ingredients as nutrient sources. Although performance of these feeds would probably be good, they would be cost-prohibitive for normal use

Protein and Amino Acids

It is common to hear the terms "carnivorous" and "herbivorous" used in reference to shrimp species and the various feeds they consume. Unfortunately, these terms are often misapplied. A carnivorous animal is one whose dietary protein consists primarily of animal protein. An herbivorous one typically consumes plant protein (e.g., primary producers such as benthic diatoms). However, to some culturists, a carnivorous shrimp is one requiring a relatively high level of protein in its feed. Protein can and is provided via a wide assortment of dietary sources of both a plant (e.g., soybeans) and animal (e.g., fish meal) nature.

Protein is usually the most expensive nutrient and feed ranges in protein content (referred to as crude protein) from around 18% (as-fed) to over 45%. For example, some of the protein "requirements" reported in the literature for various species of shrimp are: *F. aztecus*, 23-31%; *F. californiensis*, 35%; *F. duorarum*, 28-32%; *F. indicus*, 43%; *M. japonicus*, > 60%; *F. merguiensi*, 34-42%; *P. monodon* 35-5%; *F. chinensis* 40%; *F. pennicillatus*, 22-27%; and *L .setiferus*, 28-25%. The difference in protein content of feeds is often attributed to differences in protein "requirement" shown by various shrimp species. As mentioned, *Marsupenaeus japonicus* is known to grow well when fed diets containing relatively high protein concentration. Conversely, *Litopenaeus vannamei* is typically offered production feeds containing lower crude protein (approximately 30-35%). Unfortunately, many of these conclusions are anecdotal or experiential in nature.

As mentioned, the term "protein requirement" is often mistakenly used to denote feed protein content or level. Nutritionists recognize that the real issue in providing adequate protein in feeds regards three factors: 1) essential amino acid requirements; 2) overall digestibility of dietary proteins; and 3) feed consumption level. Very little information is available regarding requirements for essential amino acids by shrimp. Guidelines for inclusion of essential amino acids in shrimp feeds have largely been developed through "trial and error" over many years of production.

In terms of digestibility, shrimp feeds could be formulated to contain 50% crude protein, of which relatively little might be "bioavailable" (e.g., feather meal) or, conversely, to contain 20% crude protein, the majority being highly digestible (e.g., casein). In reality, neither of the previous scenarios apply to typical commercial shrimp feeds. The most common protein sources used in commercial shrimp production feeds are fish meal and soybean meal. These ingredients contain proteins that are reasonably well-digested (about 80%) by shrimp. Unfortunately, not all protein sources are of similar quality, even those of the same type (i.e., digestibility). For example, fish meal can range in protein content from a low of 58% to a high of around 68% (dry matter basis). For this reason, shrimp farmers need to be aware of the *quality* of proteins used in feeds. Reports on digestibility of protein sources should be made available to farmers by feed manufacturers who undertake these tests routinely.

As mentioned, achieving the protein "requirement" in feeds implies adequate consumption of the feed. Ingestion of feeds and factors contributing to ingestion must therefore be taken into consideration. Simply offering shrimp a feed that contains 30% protein, does not imply that a sufficient quantity of the feed will be ingested to meet the shrimp's protein requirement. Thus, protein "requirement" levels determined under controlled conditions with feeds containing high levels of attractants may not translate into similar growth under practical pond conditions. The estimation of protein "requirement" of shrimp necessitates understanding feed protein content, its digestibility in terms of essential amino acids and average consumption rate under various environmental conditions.

Much nutritional research is currently underway to identify appropriate protein: energy ratios by species and culture criteria. Most efforts focus on two approaches to satisfying protein "requirement": 1) by feeding shrimp diets containing a high proportion of attractants (to insure rapid, complete consumption) and minimal amounts of highly digestible protein (e.g., 15-18% crude protein); or 2) by feeding shrimp diets containing moderate levels of attractant (the protein source, itself) and higher levels (e.g., 30-35% crude protein) of moderately-digestible sources of protein. The former approach is usually taken to reduce feed waste products (nitrogen, phosphorus - typical environmental pollutants). In such diets, most feed nutrients would be highly digestible. The latter strategy emphasizes lower feed cost, but possibly requires more input from natural productivity. Ultimately, the proper use of protein in shrimp production feeds will require better understanding of many factors: requirement, consumption, digestibility, interaction with environmental factors, reduction of environmental pollutants, to name a few.

Protein/Energy Ratio

The final major issue concerning protein in commercial shrimp feeds regards its potential use by shrimp as an energy source rather than for growth. In general, protein has a "sparing" effect on other sources of energy in feeds. Ideally, protein, which is the most expensive component in feed is used primarily for growth, while cheaper components are included to meet energetic needs. If readily available sources of energy (e.g., carbohydrates) are deficient in feeds, shrimp will use protein to support metabolic functions other than growth. In this case, shrimp will continue to consume a feed (and hence the protein content) past the point needed to obtain sufficient protein for good growth in order to satisfy overall energy needs first. If a feed is over-fortified with protein, it means that some of this expensive dietary component will be used for energy; whereas, in an energy-balanced feed, most protein would ideally be used for growth. Energy content of feeds is best derived from relatively inexpensive grain sources (e.g., wheat, corn, rice). Conversely, a potential problem can also exist for feeds that are over-fortified with energy. In this case, shrimp will probably consume only as much feed as needed to meet energy needs and then reduce subsequent consumption; in this case, the protein requirement may not be met.

Lipids and Carbohydrates: Energy Sources

The most suitable sources of energy for shrimp feeds are ingredients containing relatively high carbohydrate content, typically grains. Highly digestible sugars (e.g., monosaccharides such as glucose) are not suitable as carbohydrate/energy sources in shrimp feeds due to either cost (e.g., wheat starch) or reduced/abnormal assimilation. The most suitable carbohydrate sources for shrimp production feeds are those derived from low-cost, practical ingredients (e.g., wheat flour, wheat middlings, rice bran, etc.).

The digestibility of feed carbohydrates can be increased as part of the manufacturing process, itself. The digestible energy content of identical feeds manufactured via extrusion (high temperature) can be increased over that of pelletization (lower temperature). Furthermore, certain carbohydrate sources such as wheat flour can promote feed pellet water stability and, as such, serve as good natural binders. Extrusion of carbohydrate sources at high temperature typically reduces dependence upon costly binders and, as a result, assists in reducing overall feed ingredient cost.

While lipids (oils/fats) are considered dietary energy sources, their use in purified form at high levels in feeds is generally cost-prohibitive. Lipids typically serve both as energy sources and as attractants. Purified lipid sources (e.g., fish oils) are included in commercial shrimp production diets in order to insure minimal lipid content and satisfy requirements for marine essential fatty acids. The amount of purified lipid included in a diet is determined by the amount of lipid/fatty acids provided by other dietary ingredients (i.e., most protein sources also contain lipids). The lipid concentration of most commercial shrimp production feeds is less than 8% of the diet (as-fed basis). Inclusion of lipids at a higher concentration can result in poor feed binding and, subsequently, reduced pellet water stability. Another issue concerning dietary lipid level is that of maintenance of a suitable protein:energy ratio (see above); however, quality of lipids can also impact feed quality. If improperly stored, the fatty acid component of feed lipids can undergo auto-oxidation, resulting in an unsuitable toxic/rancid condition.

Dietary Energy Content

Shrimp appear to utilize energy in feeds in a similar manner to that of terrestrial animals with the following exceptions: 1) substantial variations among shrimp species may exist based upon the ratio of plant:animal protein typically consumed, and 2) shrimp may have higher energy losses via excretion through the gills and during the molting process. The dietary requirement of energy by shrimp also appears less than that for other non-aquatic animals due to the following: 1) dietary energy is not used for maintenance of body temperature; 2) because shrimp are submerged in water, maintaining their orientation/position in water is less energy expensive; and 3) shrimp excrete ammonia and, by doing so, require no energy for formation of urea or uric acid.

There is not an abundance of information available regarding energy efficiency of shrimp feeds; however, most commercial shrimp production feeds contain gross energy coefficients of around 3.1-4.1 kcal/g[1] feed. Digestible energy:protein ratios approximating 12 kcal/g protein appear suitable for feeds offered to Litopenaeus vannamei.

Minerals and Vitamins

The minerals most commonly limiting to formulation of commercial shrimp production feeds are phosphorus and calcium. Phosphorus is unique in that it is found only as a solid and cannot be solubilized in water. It can be found in many green plants or grains in an indigestible form known as phytate or phytic acid. For this reason, when analyzed for phosphorus digestibility, only one-third to one-fourth of the phosphorus in soybean meal is considered available to shrimp. Providing adequate dietary phosphorus typically requires supplementation in a purified form (e.g., monobasic, dibasic, tri-basic phosphate). These purified forms of phosphorus also have variable digestibility. The total phosphorus content of shrimp feeds usually approximates 1.5.0-2.5% (as-fed basis), but only about 50% of that is actually available to shrimp for growth.

In the past, most nutritionists recommended that shrimp feeds contain a calcium to phosphorus ratio of 2:1 (calcium to available phosphorus). The maintenance of this ratio has proven difficult to achieve in feeds due to a tendency of most commercial shrimp feed formulations that contain excessive calcium. For this reason, purified forms of phosphorus are typically supplemented. It is also considered that sufficient calcium should be available for dietary purposes via uptake through the gills from pond water. In fact, this is probably the case for most trace or microminerals as well.

Vitamin packages (as with mineral supplementation) appear to be necessary components of commercial shrimp production feeds only when beneficial pond natural productivity prove inadequate (e.g., as sometimes occurs under very high stocking densities). Many shrimp feeds are currently supplemented with vitamin premix packages or vitamin

[1] Kcal/g = kilocalories per gram. A kilocalorie is 1,000 calories, the basic unit of the energy available in nutrients.

precursors. These are often included as precautionary amendments against infectivity of pathogenic viruses and bacteria. For example, despite adequate substantiation, carotenoids (e.g., beta carotene) are sometimes recommended for preventing epizootics. At low stocking densities (e.g., 15 shrimp per m^2), vitamin and mineral premixes are typically not included in commercial feeds. Probably the best approach to deciding upon use of a premix would require the farmer evaluate individual pond levels of natural productivity, prevalence of disease, stocking densities, and environmental factors. The lower the natural productivity, the higher the stocking density, greater incidence of disease and the more stress imparted to shrimp by adverse environmental conditions, the more likely a vitamin/mineral package would lend itself to increased production. The cost of a complete vitamin and mineral package should be taken into consideration; inclusion could increase feed ingredient costs by $30-50 per metric ton (MT).

Non-nutritional Feed Ingredients

The term *non-nutritional feed ingredient* typically refers to items such as binders, antibiotics, antioxidants, preservatives and pigments. Binders are included in feeds to insure pellet nutrients do not leach from the feed prior to its consumption. It is important to note, however, that suitable binding is also determined by the pellet manufacturing process, not simply the binder. Extent of binding is determined by ingredient particle size, conditioning time and temperature, die characteristics, and cooking/drying temperatures. Further, binders used for preparation of feeds used in land-based production operations (e.g., beef cattle, poultry, swine, etc.) are not typically adequate for water-based feeds.

Antibiotics are often added to feed to combat infection of shrimp by bacterial pathogens. Commercial shrimp production feeds supplemented with antibiotics are typically referred to as "medicated feeds" and often contain 2,000 - 4,000 mg/kg of one of the following antibiotics: oxytetracycline, oxalinic acid, sulfamerazine, sulfonamides, to name a few. Although addition of antibiotics to feeds results in an increased expense of about $50/MT, they are typically fortified in excess to insure post-manufacture dosage criteria. Currently, much concern has been voiced regarding the unsubstantiated overuse or over-fortification of feeds with antibiotics. Consistent use of antibiotics in medicated feeds can lead to resistance on the part of bacterial pathogens and can disrupt the trophic hierarchy of fragile estuary ecosystems once incorporated. For these reasons, the use of antibiotics in shrimp feeds is currently prohibited in the U.S. This has led to an increase in research focusing on supplementation of aquaculture feeds with probiotic bacteria for control of disease, particularly vibrioses.

Feed preservatives are chemical compounds included in commercial production feeds to guard against aflatoxin, a toxin generated by the mold, *Aspergillus flavius*. This mold requires high moisture (greater than 14%) conditions for growth and is typically isolated from grains. These are the same grains used as carbohydrate sources in shrimp feeds. Because aflatoxin is heat-stable, it can be passed on to shrimp via feeds, possibly resulting in mortality due to aflatoxicosis [2]. Most reputable feed mills rigidly monitor incoming raw materials, especially grains, for presence of aflatoxin. The preservative commonly used to

[2] Aflatoxicosis = poisoning by aflatoxin.

prevent spread of *Aspergillus flavius* in feeds is proprionic acid (proprionate), included in feeds at a level of about 0.5%.

Antioxidants are added to feeds to prevent oxidation/rancidification of fatty acids. Fatty acids (found in dietary lipids) and vitamins, if exposed to air, can oxidize to form peroxides and other toxic compounds. Should this occur, the requirement for essential fatty acids could possibly not be met by the feed and growth would be compromised. Further, it is unlikely that the feed would be consumed at a normal rate and, if consumed, could be toxic to shrimp. The most commonly used antioxidants in feeds are butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT). Other antioxidants can be found as naturally occurring compounds in shrimp feeds: these include vitamins E (ethoxyquin, a tocopherol) and C (ascorbic acid).

Pigments are used in shrimp feed primarily to convey appropriate color to shrimp. One of the most common is astaxanthin a common pigment derived from beta carotene and found in shrimp and crab meals.

Physical Characteristics of Feeds

Feed *physical* characteristics usually refer to any attribute that might affect its manufacture, appearance or integrity of feed when it is submerged. Physical characteristics include factors such as color, water stability, ingredient particle size (extent of grinding of pellet ingredients), pellet size and, to a certain extent, attractability.

Feed Color

The color of a pellet is not important to shrimp in terms of attractability or eventual consumption, but is indicative of ingredient composition and quality of manufacturing. Most commercial shrimp production feeds are dark brown in color due to not only to the heat of processing but also feed ingredient color (most are relatively dark in color). Sometimes feeds become lighter in color due to exposure to long-term excessive heat and direct sunlight.

Feed Water Stability

Most commercial shrimp production feeds have binding characteristics that allow for pellet stability of about 4-6 hours pellet stability. Increased pellet stability is of little economic value to feeds since most feed attractants are lost within this amount of time. The binding of most feed pellets is accomplished by proper manufacturing procedure (see previous section), inclusion of ingredients having natural binding potential (e.g., carbohydrates such as wheat flour) or by addition of artificial compounds (e.g. synthetic polymers). The pellet binding potential provided by natural dietary sources alone is usually inadequate for proper binding. Most artificial binders are added to feeds at a rate of about 0.5-1.0% of the diet. There is an indirect relationship between binder cost and binding capacity.

Ingredient Particle Size

Most feeds utilize ingredients that have been ground and passed through at least a 500 micron (*u*M, 35 mesh) sieve. The need for grinding feed ingredients to a small particle size is that: 1) it enhances binding and physical formation of the pellet as it passes through the die; and 2) due to the way shrimp consume food items, they are not capable of rejecting/selecting small particles (shrimp can select out particles as small as 10*u*M in diameter). Further, all feed particles are included in pellets for a reason. Any losses prior to consumption could equate to inadequate nutrition (at least with respect to nutritional ingredients). Note: If you can pick up a feed pellet and easily identify large particles, its manufacture did not include adequate grinding and may equate to loss of availability of nutrients to shrimp.

Feed Pellet Size

Although feed pellet size selection is often considered a feed management issue, it is also a physical attribute of the feed. Feed particles can range in size from very small (less than 50 *u*M, as a larval diet) to over 1/8 inch diameter (some maturation feeds). Most, however, are relegated to 3/32 inch diameter. From this base diameter, almost all commercial feed particle sizes are derived. The manufacture of fine, medium and coarse crumbles (approximately 0.5 mm, 1.0 mm and 2.0 mm, respectively) involves fracturing 3/32 inch diameter pellets with a roller type crumbler. The "fractured" particles are then separated into the three particle size classes by a shaker sieve. If feed ingredients have been adequately mixed, all particles within the pellet will have similar nutrient composition. The use of various-sized feed pellet/particles is described in a subsequent section.

The logic behind offering smaller feed pellets to smaller shrimp is concerned with both shrimp feeding behavior and adequate feed distribution. Shrimp consume feed pellets individually, grasping them in ventrally-located feeding appendages, macerating the pellet with their mandibles. Shrimp must also be able to easily locate feed pellets. The offering of too small a pellet per unit body weight of shrimp increases effort to locate multiple pellets and is not energy-efficient. Proper distribution of feed requires that rations be distributed in ponds in areas of high shrimp density, so that shrimp do not expend an inordinate amount of energy locating pellets. If too large a pellet is used, all shrimp might not locate a pellet. Appropriate management of feed pellet size is discussed in the feed management section of this text.

Storage of Shrimp Feeds

For large shrimp farms, receiving and storage of feeds is a common activity. Feeds are delivered to most farms in polypropylene bags transported in large, container-sized shipments. One 40 foot container will contain 450 bags of feed, each weighing 100 pounds. Often, more than one container of feed is delivered to the farm simultaneously; thus, farmers need to be prepared to quickly offload this feed and store it in an appropriate facility. The proper storage of feeds requires development and use of a comprehensive inventory system in which incoming and outgoing (to the ponds) feed is carefully accounted. "Old" bags should be used prior to newly-arrived ones and daily records must be maintained as to feed destination. The use of feeds older than three months post-manufacture is not recommended. The economic loss of production resulting from offering a feed that has lost nutritional quality due to aging is probably equal to that of replacing the feed. When in doubt, get rid of the feed. Old feed can become contaminated with aflatoxin (especially if stored in a humid environment) and be rendered deficient in terms of vitamins and minerals due to exposure to high heat or light conditions.

Incoming feeds should be stacked on pallets above the concrete floor of the feed storage building. Stacks should be separated by about 15-20 cm in order to achieve proper ventilation. If feed turnover is rapid, bags can be stacked in high layers (up to 15-20 bags); however, if feed use is slow, another pallet should be inserted into stacks every five to seven layers. All bags should contain labels verifying manufacturer, date manufactured, mill location, proximate analysis, and list of ingredients. Feed manufacturers will often identify bags of medicated feed by simply writing in magic marker on the side of the bag. Insist that all bags be accurately tagged.

The feed storage building, itself, should be constructed of either corrugated metal sheeting (walls, roof) or have concrete walls. The floor should be constructed of concrete and capable of being swept or washed down on a daily basis. The ceiling should be reasonably high to allow for efficient stacking of feed bags and convection of heat to the top of the building. The main design objective for feed storage buildings is to avoid moisture from rainfall and to aid in the removal of heat. Many farm feed storage buildings are constructed with a ventilation roof (small double roof) for convective removal of heat.

Feed Quality Assurance

Feeds should be routinely evaluated by farm technicians to ensure consistent quality. Poor quality feed pellets will ultimately result in poor feed performance (i.e., poor growth) and deterioration of pond bottoms. In order to accomplish this, random samples should be taken of all feed shipments entering the feed storage building. Feeds should be visually inspected for excess moisture and/or presence of mold: If newly-arrived feed pellets are moist but not contaminated by a greenish-brown mold (*Aspergillus flavius*), it can be assumed that the excess moisture was acquired during transport. Any mold-contaminated feed arriving directly from the feedmill should be returned within 24-hours. As mentioned, feed pellets with surface mold should not be distributed in ponds.

Random samples should also be taken from each feed shipment for evaluation of feed water stability and percent floatation according to the following:

1) Drop a random handful of pellets into a 20 liter bucket containing ten liters of pond water;

2) After one minute, estimate the percentage of floating pellets;

3) At two hour intervals, evaluate pellet stability until pellets have either disintegrated or have been submerged for six hours.

Pellet stability evaluations should be recorded using a numeric scale; where 10 represents a hard, intact pellet, and 1 represents total disintegration. After two hours' evaluation, the evaluation interval can be increased to hourly. Unfortunately, this test is highly subjective; therefore, the same person should perform the test each time.

In addition to the previous testing, pellet samples should be routinely sent to independent analytical laboratories for determination of proximate analysis. Most large farms will undertake these analyses every three months. Results should be compared to corresponding values provided by the feed mill. Farms should purchase feeds only from established feed mills with adequate references. Note: The protein content of feeds is determined indirectly and is based on total nitrogen content. It is therefore possible to encounter "high protein" feeds containing little or no actual protein since inclusion of nitrogenous products such as urea can be erroneously interpreted as protein.

Production Efficiency of Commercial Shrimp Feeds

Feed prices vary, but current price for 35% protein shrimp feeds in the U.S., if purchased in bulk, range from US$0.27 to US$0.31/lb. Many feed companies offer feeds containing lower quality ingredients (generally, lower quality equates to lower protein content); however, higher quality feeds are often promoted by implying their use will result in higher feed conversion rates (FCR's). This is usually true. For example, many feed companies in the Eastern Hemisphere promise FCR's of around 1.8 (lbs feed:lb heads-on shrimp produced) with a concomitant growth rate of 3 g/10 days for *P. monodon*, for use of their top-line feed (growth rates for *P. monodon* are typically higher than those for western hemisphere species). Their lower-grade feeds might generate FCR's of around 2.5:1. On the other hand, western hemisphere feed companies generally do not guarantee specific weight gain, but offer extension services for optimization of feeds. For shrimp farms in Central and South America achievable FCR values can range between 1.2 and 1.8. Of course, the higher the stocking density, the more difficult it is to reduce FCR values. There are indications, however, that low FCR's can also be achieved under high density zero water exchange conditions and elevated aeration (20-40 hp/ha) with typical commercial shrimp production feeds.

Feeding Strategy

A common observation of shrimp feeding behavior is that shrimp consume pellets for a relatively short time post-introduction to the pond. This unconsumed (refused) portion of the ration continues to decompose via hydration and biological/microbial activity. In some cases, the refused portion of the feed can exceed 60% of that offered. Despite failure to consume feed, shrimp can still benefit nutritionally from this process. For example, up to 75% of pellet carbon can be assimilated by other benthic organisms (e.g., bacteria, diatoms, polychaetes, copepods, nematodes, protozoa, etc.) which can, in turn, indirectly provide carbon as well as other nutrients to shrimp.

The point at which feeds should first be applied to ponds is an issue for which most shrimp farmers have an opinion. Most farmers add a small amount of feed around the edge of the pond, especially in the areas to which postlarvae have been stocked. This ration is not meant to provide all nutrition to the postlarvae; instead, it is largely meant as a supplement to natural productivity should pond zooplankton levels be inadequate and as an appetite stimulant. Regardless, ponds should not be stocked with postlarvae unless natural productivity has been well established. As mentioned, in well-prepared ponds where natural productivity has been enhanced via fertilization, a substantial portion of nutrition can be derived from non-feed sources.

In situations where juvenile shrimp (0.8-1.0 g) are stocked at relatively high density (e.g., above 20-25 juveniles/m^2), feeds should be applied 24 hr prior to stocking. In this case, the high initial biomass density of shrimp warrants supplementation of natural sources of nutrition. A general rule of thumb for pelleted feed application is that once pond shrimp biomass exceeds 200-300 kg/ha, rations should be applied. Subsequent feed rations should follow a general feeding guideline until biomass and feed consumption data are available (see subsequent discussion).

Feeding Frequency

Since commercial production ponds are relatively shallow, shrimp activity during the day is significantly reduced. During this time, it appears that almost the entire population migrates to deeper areas of the pond and partially burrows into the soft bottom muds. Feeding during periods of increased activity (i.e., nighttime) could result in better feed consumption and, in-turn, enhanced feed conversion rate (FCR).

The most efficient utilization of feed requires addition of rations at more frequent intervals throughout the night when shrimp activity is highest; however, in large commercial operations, this strategy is neither practical nor cost-effective. Since feed is a major operational cost, attempts should be made to rigidly manage its use. Detailed supervision is very difficult to accomplish at night due to limited visibility. For this reason, it is more practical to feed at least once during daylight hours. The first feeding should begin no earlier than 16:00 hrs, and, with an adequate number of personnel, should be terminated by 18:00 hrs. If a second feeding is scheduled, it should begin in the early morning (02:00 - 04:00). Feed left unconsumed as a result of the second feeding will probably be indirectly available as detritus for the remainder of the night when shrimp activity is high.

Controlled feeding trials have been undertaken to determine optimum feeding frequency for farmed shrimp. Under very low natural productivity conditions (where external, non-feed sources of nutrition are limited), shrimp growth rate should increase with feed frequency. Studies under moderate natural productivity conditions have shown that four to six daily feedings improved growth rate over lower frequencies; however, there was no significant improvement in growth rate for shrimp fed more than four times daily. As mentioned, it is not practical to feed large grow-out ponds more frequently than twice daily. Improved feed performance can probably be more easily derived from a better understanding of the role of natural productivity in pond nutrition than via increased feed frequency. Note: in aerated super-intensive ponds stocked with 60 shrimp per m^2, FCR values approximating 1.5:1 have been possible with only two daily feedings (Samocha, personal communication).

A final issue regarding feeding frequency regards the effect of temperature upon feeding schedules. When water temperature drops below 25 °C, *L. vannamei* will burrow into the pond bottom muds. Subsequent feed consumption rate typically declines as a result of decreased metabolism. As mean temperature minima decrease on the farm during the transition from wet season to dry season, feeding times must be adjusted. In order to provide feed during times of highest shrimp activity, most feeding schedules have to be shifted to earlier in the evening or later in the morning.

Feed Distribution

It is extremely important that feed pellets be distributed uniformly over the entire pond area. Feeding small areas of the pond bottom in which shrimp biomass density is high results in increased competition for feed pellets and exerts unnecessary stress on shrimp populations. In some cases (see subsequent section on Peruvian feeding tray methodology), farms will deposit the entire pond feed ration on feeding trays. However, these trays are, themselves, evenly distributed across the pond bottom. Again, the objective is to bring the feed to the shrimp, minimizing energy associated with finding the feed.

Different feed distribution strategies have yielded variable degrees of success. Aerial feed application can result in exceptionally uniform coverage over the entire bottom area of the pond, but is generally cost-prohibitive. Land-based feed blower equipment (Figure 1) cannot disperse feed over the entire surface area of a typical commercial-sized grow-out pond and is generally limited to the within 15 m from the edge of the pond. The same blower apparatus mounted on platform boats may prove more efficient, but may require the purchase of multiple units. If one blower unit is used on all ponds, movement from pond to pond could prove problematic.

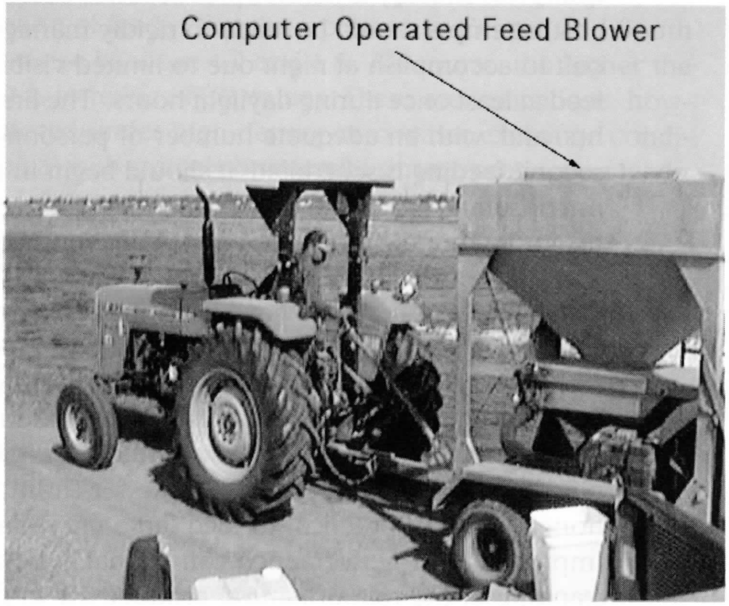

Figure 1. Computer operated feed blower pulled by a tractor.

Although labor intensive and relatively inefficient, manual broadcasting of feed from boats in a zig-zag pattern over the entire surface area of the pond is the most common method of feed distribution. Unfortunately, this method requires a conscientious effort to ensure that the entire bottom area receives feed regardless of the daily dosage of a particular pond. Further, feed personnel must be rigidly supervised, especially when feeding at night.

Feeding Guidelines

There have been several feed guideline tables published for calculating the quantity of feed applied to commercial shrimp production ponds. These guidelines equate daily feed ration to a percentage of the pond shrimp biomass fed as dry weight feed. The basis for developing feeding guidelines is relatively simple: a rapidly growing juvenile shrimp will generally consume more feed per unit body weight than a larger, slower-growing sub-adult.

Another point: feed guidelines are really no more than guidelines. Estimation of daily feed rations cannot be strictly the result of a mathematical calculation (although some farmers think so!). As mentioned, there are multiple compounding factors either directly or indirectly affecting growth of shrimp: water quality, physiological state of the shrimp, extent of primary and secondary production, etc.

Since the determination of daily feed ration is relatively subjective and potentially costly to semi-intensive commercial operations, it should be derived only by experienced personnel. In other words, feed should be used conservatively. Further, improperly administered feed could increase environmental pollutants. Overfeeding often results in contamination of pond bottoms, yielding increased biochemical oxygen demand (BOD). The resultant decrease in DO could lead to reduced feed consumption and, ultimately, increased mortality. Prolonged "overfeeding" can result in a build-up of hydrogen sulfide in anaerobic pond sediments. This can also cause increased mortality or cause shrimp to go "off feed" for extended periods. Ultimately, large areas of the pond bottoms may have to be chemically oxidized to eliminate hydrogen sulfide.

Conversely, underfeeding could result in reduced growth rates and increased mortality due to elevated stress and/or secondary infections. The feeding guidelines that follow have been developed based on results from successful commercial semi-intensive shrimp farm operations.

Table 1. Feeding rate as percentage body weight for postlarvae and juveniles stocked in nursery ponds at 150-200 postlarvae/m².

Mean Shrimp Wt. (g)	Feeding Rate (% body weight fed as dry weight feed per day)
0.15	19.00
0.20	17.80
0.25	16.30
0.30	15.00
0.35	13.70
0.40	12.30
0.45	10.90
0.50	9.90
0.55	9.20
0.60	8.60
0.65	8.20
0.70	7.80
0.75	7.50
0.80	7.30
0.85	7.10
0.90	6.90
0.95	6.70

Table 2. Determination of feed ration per body weight of shrimp for grow-out ponds stocked with juveniles at 6.5-9.0 juveniles/m².

Mean Shrimp Wt. (g)	Feeding Rate (% body weight per day)
1.0	6.00
1.5	5.33
2.0	4.83
3.0	4.23
4.0	3.80
5.0	4.00
6.0	3.80
7.0	3.43
8.0	3.20
9.0	2.66
10.0	2.57
11.0	2.43
12.0	2.33
13.0	2.23
14.0	2.10
15.0	2.00
16.0	1.93
17.0	1.87
18.0	1.80
19.0	1.73
20.0	1.69
21.0	1.66
22.0	1.59

Table 3. Determination of feed ration per body weight of shrimp for grow-out ponds stocked directly at 12.5-18.5 postlarvae/m^2.

Mean Shrimp Wt. (g)	Feeding Rate (% body weight per day)
0.008	7 lbs per ha per day
2.0	7 lbs per ha per day
2.0	5.50
3.0	4.65
4.0	4.22
5.0	3.90
6.0	3.60
7.0	3.27
8.0	3.00
9.0	2.85
10.0	2.75
11.0	2.63
12.0	2.55
13.0	2.50
14.0	2.41
15.0	2.30
16.0	2.25
17.0	2.19
18.0	2.10
19.0	2.00
20.0	1.95
21.0	1.88
22.0	1.80

Effective utilization of these tables depends upon accuracy of population estimates and mean body weight determinations due to feed ration tables being expressed as a percentage of body weight per day. Tables 4, 5 and 6 show estimated survivals as a function of average weight and time in days.

Table 4. Estimated survival of shrimp by age and weight in nursery ponds.

Days	Mean Wt. (g)	Survival %
1	0.01	100
7	0.09	80
14	0.18	78
21	0.35	75
28	0.60	73
35	0.80	70

Table 5. Estimated survival of shrimp by age and weight in grow-out ponds stocked with 0.8 g juveniles.

Age (weeks)	Mean Wt. (g)	Survival %
1	0.80	100
2	1.20	95
3	1.80	90
4	2.80	86
5	3.80	85
6	4.80	84
7	5.80	83
8	6.80	82
9	7.80	81
10	8.80	80
11	9.80	79
12	10.80	78
13	11.80	77
14	12.80	76
15	13.80	75
16	14.80	74
17	15.80	73
18	16.80	72
19	17.80	71
20	18.80	70

Table 6. Estimated survivals of shrimp by age and weight in directly-stocked grow-out ponds.

Age (weeks)	Mean Wt. (g)	% Survival
1	0.10	100
2	0.12	90
3	0.25	85
4	0.50	83
5	1.20	80
6	2.10	78.5
7	3.02	77
8	3.93	75.6
9	4.83	74.2
10	5.75	72.7
11	6.65	71.3
12	7.56	69.8
13	8.47	68.3
14	9.38	66.9
15	10.28	65.4
16	11.20	64.0
17	12.10	62.5
18	13.00	61.0
19	13.92	59.6
20	14.83	58.1
21	15.73	56.7
22	16.64	55.2
23	17.55	53.8
24	18.46	52.3

The calculation of daily feed ration incorporates data from two tables. For example: A pond has been stocked with juveniles at 85,000 juveniles per hectare (8.5 juveniles/m^2). The mean weight of shrimp in the population has been determined as 9.5 g. Since the pond has been stocked with juveniles, one should refer to Tables 2 and 5, and perform the following calculation:

1) (85,000 juveniles/ha) x (80.5% survival) = 68,245 (juveniles/ha surviving);

2) (68,245 juveniles/ha x 9.5 g/juvenile*)/1,000 = 650 kg juveniles/ha;

3) (650 kg juveniles/ha) x (2.63% feeding rate**) = 17 kg feed/ha/day.

* Table 5; average weight of population between 9.00 and 9.93 grams.
** Table 2; ratio of daily feed to body weight when average weight of population is 9.5 g.

Therefore, the pond should receive a daily feed ration of 17 kg.

Once the feed ration has been determined, it is necessary to ascertain whether resultant average weekly weight gains are adequate. Gains of between 0.85 and 1.20 grams per week are probably adequate; however, should weekly weight gains fall below 0.70 grams, there is a possibility that the pond is being underfed as a result of better survival or an "overstocking" error. This could lead to an under-calculation of feed rations. On the other hand, if average weekly weight gains are between 1.3 and 2.0 grams, the staff should be alert to the possibility of "overfeeding" as a result of lower-than-anticipated stocking densities.

Feed ration calculations should be performed on a weekly basis for all ponds for efficient monitoring of shrimp growth and feed conversion. Poor feed management may not only affect growth and survival, but also significantly increase production costs. If feed ration calculations are performed bimonthly, the risk of poor management problems is increased.

When calculating feed rations for juveniles in nursery ponds, Tables 1 and 4 should be utilized. Feed rations for directly-stocked production grow-out ponds are determined from Tables 3 and 6.

Feed Management

Although there are many feeding guidelines established for estimating feed application to ponds, arriving at an appropriate and manageable feeding program is critical for economizing feed usage. In reality, a good feeding program is one in which shrimp remain slightly underfed. The benefit of this is two-fold: 1) shrimp are more easily attracted to feed pellets and consumption better reflects actual demand; and 2) there is reduced potential for decreasing quality of pond benthic sediments through decomposition of excess feed. Shrimp will probably make up for feed dietary intake deficiencies by consuming detritus; thus, detritus levels in ponds are also effectively managed.

In order to more accurately assess whether shrimp are being properly fed (i.e., slightly below satiation), most farmers utilize feeding trays. As mentioned, feeding trays should be located throughout the pond in areas where shrimp locate during times of feeding. If feeding times are coordinated with even distribution of shrimp, then trays should be evenly distributed. Consequently, it would not be appropriate to locate feeding trays in the shallow end of a pond if feeding takes place primarily during the day. The proper location of feeding trays is an issue that sometimes requires multiple production cycles to develop.

The number of feeding trays used in ponds appears to be inversely proportional to stocking density. For most semi-intensive ponds, one or two feeding trays per hectare of pond water surface area is recommended. More feeding trays could be installed, but eventually, with increased numbers, the management of these trays could become complicated and costly (in terms of additional personnel).

Basically, there are two well-documented, albeit somewhat different, approaches to using feeding trays: 1) as diagnostic indicators of feed consumption (typically smaller trays); or 2) as both an indicator of feed consumption and as a feed "container" (larger trays in which the entire feed ration is placed on or within the tray). What follows is a description of these two methods of feed tray use.

Feeding Trays for Evaluating Consumption

The small trays used for determination of shrimp feed consumption are typically round or square and about 70 cm in diameter or length, respectively. The tray frame is constructed either of ½ in. or ¾ in. PVC. In order to facilitate sinking of the tray through the water column, frames are filled with pea gravel or sand. Feed is held within the frame by attaching simple mosquito netting of appropriate mesh (i.e., smaller than feed diameter) to the frame. The tray is suspended by four equal-length lines attached to a stronger main line. This allows for level sinking, without tipping or loss of feed. The main line is typically connected to a piece of white styrofoam float for easy identification at night. As mentioned, about 2 trays per ha of pond water surface are used for semi-intensive ponds (Figure 2).

Figure 2.
Feeding trays can be used to simply monitor feed intake, in which case smaller trays are used, or all the feeds can be distributed on larger trays.

To each small feeding tray about 150-200 g of feed is added at the same time the regular feeding is conducted. Two hours after feeding, all trays within a pond are quickly examined for residual (uneaten) feed. This wet feed weight is difficult to estimate in comparison to dry feed weight; therefore, most feed managers will work with feed personnel to assure accurate estimation of uneaten feed. This is accomplished by weighing individual volumes of dry feed in 50, 100, 125 and 150 g amounts and submerging them in feeding trays in a typical pond (without shrimp). After 2 hours, trays are removed and residual feed volumes are compared. With time, feed personnel become quite proficient at estimating residual feed.

Most farmers establish a guideline for application of feeding tray information to subsequent feed rations. This requires determining the average estimated amount of residual feed in trays (as a percentage of 150 g of feed used for the test) for a specific pond. This percentage is then applied to a prescriptive table indicating how subsequent feed applications should or should not be modified. The following table is an example of a feeding tray guideline (Clifford, 1992).

Table 7. Feeding Tray Guideline

Average amount of residual feed remaining on trays (%)	Adjustment to Subsequent Feed Ration
0	Increase 5%
<5	No change
5-10	Decrease 5%
10-25	Decrease 10%
>25	Suspend 2 feed rations; re-initiate at 10% less

If residual feed levels remain excessive, some farmers will suspend feeding until "normal" feed consumption resumes. Other farmers expand upon the scale from 0 residual to >50% residual.

There are multiple explanations for variance in shrimp feed consumption rates estimated by feeding trays. Sudden changes in water quality (especially salinity) often cause shrimp to molt, reducing feed consumption rate. Feed consumption rate might also increase slowly over time as a result of shrimp associating feeding trays with the presence of feed. A decline in temperature minima to below 25 °C could decrease feed consumption rate.

Information from feeding trays can also be used to estimate feed conversion rates and set shows that weekly feed conversions are gradually increasing in all ponds, global feeding guidelines can be re-adjusted to limit FCR. By gradually fine-tuning tables, the risk of over-feeding ponds is substantially reduced. Further, FCR values are more appropriate. This approach to long-term feed management is currently used in most intensive zero water exchange production systems. Ultimately, improved feed management can lead to long-term savings in feed purchases.

Feeding Trays (Peruvian Style)

Many shrimp farmers who started out using small feeding trays as indicators of feed consumption have modified their use to that of containers holding the entire feed ration for a pond. That is, all feed applied to the pond is placed within these large, strategically located feeding trays. This method is also known as the Peruvian method due to its development on farms there. The probable reason for this change in strategy is an interest in further reduction of feed costs via better FCR values. Further, if all feed is applied only to cages, the potential for buildup of uneaten feed in "dead" areas of ponds is reduced. Once the pond is drained for harvest, pond preparation and refurbishing are expedited.

By the Peruvian method, the number of feeding trays located within a pond approximates 20 trays/ha for ponds stocked in the 15-20 shrimp per m^2 range. Many farmers also recommend increasing feeding tray density once shrimp increase in weight beyond 10 g.

Feed management via Peruvian-style trays is best described by the following example from Viacava (1995). For a pond with a biomass density of 1,000 kg/ha in which feed consumption approximates 20 kg/ha/day. This pond should have 20 feeding trays receiving three daily rations; thus, each feeding tray receives 333 g of feed per ration. Feed personnel receive 250 g of feed with instructions that if, after feeding, the tray is empty, an additional 50% should be added to the next ration (333 g x 1.5 = 500 g). If feeding trays are not empty, it means that either the tray is inappropriately located or some large-scale physical factor is causing substantial reduced consumption.

The benefits associated with the Peruvian methodology are largely related to increased feed efficiency. Average FCR values reported in Peru via this method approximate 1.2:1 (Viacava, 1995). The downside of this management technique is that it requires increased farm personnel for application and management of feed: On the average, one feed operator can manage one 10 ha pond per ration. If multiple rations are prescribed, then a medium-sized farm could employ up to sixty personnel associated with feeding tray management.

Feed Pellet Size Guidelines

As mentioned previously, larger shrimp are typically fed larger (and longer) feed pellets. As might be expected, almost every feed company has their own recommended guideline for pellet use. Table 8 shows a general guideline for feed pellet size vs. age of shrimp. Generalized pellet proximate analysis is also shown.

Table 8. Feed pellet size and general nutritional characteristics by shrimp weight.

Characteristic	Juvenile	Starter	Grower	Finisher
Shrimp Weight (g)	0-0.35	0.35-4.00	4-18	18-23
Pellet size	Fine, medium, Coarse crumble	Short pellet	Medium pellet	Long pellet
Pellet diameter	0.5, 1.0, 2.0 mm	3/32 in.	3/32 in.	3/32 or 1/8 in.
% protein	35	30-35	25-30	25-20
% lipid	8	8	6	5
% fiber	3	3	3	3
% ash	7	7	7	6
% moisture	10	10	10	10
Gross energy (kcal/kg)	3,500	3,500	3,200	2,800

Routine Biomass/Growth Assessment

There are many visual indicators utilized to approximate pond shrimp biomass and growth. Management miscalculations, such as insufficient feed ration, insufficient water exchange, excess fertilization, etc. could directly affect growth. Certain physiological abnormalities in the shrimp caused by the above or other alterations in the pond environment should be evaluated by observation of living shrimp samples during the routine weekly biomass sampling. When such observations are properly analyzed, corrective management procedures can be implemented.

Direct observation of a relatively large number of shrimp from a particular pond (>400 animals) is ideal for estimating growth. Although a sample of 400 animals may not constitute a statistically representative sample of the pond population, it is sufficient for establishing general trends in the population.

Sampling Protocol

In order to assure successful and accurate biomass sampling, certain steps should be taken before stocking the pond. The sites where sampling will be conducted should be chosen before filling the pond and marked by stakes. An area of 3 meters around these stakes should be cleaned of litter and vegetative growth that could later snag the cast net and affect the accuracy of the sample.

Sampling may occur as early as 10-15 days after stocking in order to check the physiological condition of the shrimp, but to assure accuracy, sampling for biomass estimation is best initiated 30 days after stocking or when the shrimp weigh about 2 grams. At this point, sampling should take place every week or every two weeks, depending on the needs and the capacity of the farm to carry out a program of sampling.

All nets used for sampling should be of uniform size and make. Sampling should be conducted using a cast net with a radius of 2 meters (which has an area of 12 m) and weighs between 6 and 8 pounds. The mesh size of the net should be ¼ inch thus allowing the capture of small shrimp. Even with a small mesh size, a significant number of small shrimp may escape during the early phase of a sampling program. The number of animals captured per meter squared will show an increase over time because of this tendency. This must be taken into consideration when using the biomass estimate as a basis for feeding calculations.

Since capture frequency is strongly influenced by lunar phases, the lunar phase corresponding to each weekly growth sample should be identified. During spring tides (new and full moons) shrimp display strong nocturnal migratory activity. At these times shrimp are relatively easily sampled and a good representation of mean weight of shrimp can be obtained. Some farmers believe that molting is influenced by the lunar cycle. Molting could influence sampling results since shrimp tend to burrow during this period. Regardless of whether molt and the lunar cycle are related, it is important to routinely note the number of captured shrimp that are molting so this may be taken into consideration in estimating trends in biomass over time.

It is important that the person throwing the cast net be the same person each time in order to obtain consistent results. This person should attempt to conduct each sampling as uniformly as possible. Other factors which may influence the uniformity of sampling should also be taken into consideration, such as:

- Water level should always be between 60 and 80 centimeters
- Avoid disturbances such as the use of outboard motors
- Maintain silence while sampling
- Each throw of the cast net should land in a new area
- If the cast net is badly thrown so that the number of shrimp captured will be inaccurate, the next throw of the net should be in an adjacent area.

Records and Data

A record of the following should be kept:

1. area of the cast net
2. % reduction in area of the cast net when thrown
3. Corrected area of the cast net (based on 1 and 2)
4. Pond identifier
5. Pond area (ha)
6. Stocking density (postlarvae/ha)
7. Number of shrimp capture per throw

8. Number of shrimp captured/m2
9. Correction factor
10. Survival
11. Estimated population
12. Average weight
13. Estimate biomass

While conducting routine weekly growth sampling, captured animals should also be evaluated for gross signs of physiological stress. Absence or presence of these signs can indicate general physiology/disease status for a reasonably representative majority of shrimp in the pond. It is important to note that sampling should not be relegated to a select group (e.g., those around the perimeter of the pond). General physiological conditions should be recorded and reported to the farm manager. The following criteria should be used in reference to sample observations.

The extent of gut fullness is a good indicator of whether shrimp are consuming feed pellets. By holding shrimp toward a strong light (the sun or in front of a strong flashlight), gut fullness can be easily determined. The percentage value recorded should be a rough estimate of the percentage of fullness for the majority of the shrimp captured. Since these evaluations are subjective, approximate values should be used as opposed to precise determinations. A scale of 75-100% full, 50-75% full or 25-50% full can be employed.

Healthy shrimp should display active feeding responses resulting in full guts. Digestive tracts less than 75% full may indicate reduced feed consumption due to stress, inadequate feed rations, or improper sample time (e.g., sampling during mid-day when feeding activity is reduced).

As mentioned, shrimp are omnivorous benthic scavengers and characteristically graze along the bottom of ponds consuming benthic filamentous algae, invertebrates, detritus, bacteria, and pelleted feed. If the majority of shrimp in a particular pond have shown chronic slow growth, low percent gut fullness, with no sign of stress, and benthic sediment analysis shows low productivity, then it is likely shrimp are being underfed. If shrimp show slow growth and it is suspected that feed nutritional quality is deficient, more sophisticated evaluations should be conducted.

Shrimp characteristically store lipids and carotenoids in the hepatopancreas for future energy needs during times of low food availability. Lipid is stored as vacuoles (i.e., droplets) which can be readily identified within hepatopancreas tubules under normal light microscopy (100x magnification as a wet squash mount). Quantifying the extent to which hepatopancreas tubules contain lipid vacuoles is rather time consuming; therefore, subjective ratings reflective of general content are employed: Take a sample of shrimp (5-10) from a pond with reduced or slow growth and from a pond showing good growth. Compare the concentration of lipid vacuoles in the hepatopancreases of both samples. Shrimp with hepatopancreases containing high concentrations of lipid vacuoles are generally considered to be in good health and feeding aggressively.

Other items indicative of general shrimp health are molt frequency, extent of fungal infestation, presence of chitinous bacteria on cuticle, antennae length, gill coloration and anatomical abnormalities.

Shrimp ponds should also be examined for presence of excess feed, typically found in two forms: 1) floating, decomposed feed, approximately 48 hours old, and 2) uneaten or disintegrated pellets on pond bottoms. The presence of excess feed should be closely monitored as it indicates poor feed management technique and may result in significant financial losses through poor feed conversions. Any observations relating to excessive feed should be immediately reported, and corrective measures implemented.

On occasions when pond oxygen levels drop to less than 3.0 ppm, feed reductions will be made. General reductions in feeding based on pond DO levels should only be made with consent of both farm and water quality managers. Reductions are modified on the basis of how quickly DO levels respond to photosynthesis, fertilization and increased water exchange. The following guideline is proposed for feeding rate modifications resulting from low DO. If the early morning DO reading is 2.5 - 2.9 ppm, reduce the next ration by one-half. If the early morning DO reading is 2.0 - 2.4 ppm, skip the next ration and check DO level again at about 10:00 hours. If the 13:00 reading is less than 5.0 ppm, do not feed the pond until the next day. If the 13:00 reading is 5.0 - 7.0 ppm, feed only a half ration for the first evening feeding. If the 13:00 oxygen reading is over 7.0 ppm, feed the full evening ration. When the early morning DO reading is less than 2.0 ppm, no feed is given to the pond until the next day.

Concluding Remarks

In general, most shrimp feeds available to farmers are of excellent quality and manufacturers are quite willing to offer assistance in proper pond feed management. Substantial savings in feed use can be made in the evaluation of feed consumption and by simple precautions such as proper feed storage. However, the largest savings in feed costs for semi-intensive farms can be secured via proper management of water quality, especially with respect to adequate levels of natural productivity. Proper feed management also helps maintain soil and water quality, as well as effluent quality.

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5

FERTILIZATION

Fertilization

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Introduction

The objective of fertilization is to encourage growth of plants (phytoplankton and algae). These organisms constitute the first step in the food chain of the pond ecosystem (see Chapter 1). Phytoplankton are responsible for converting solar energy and nutrients into biomass and this process is referred to as *primary productivity.* Phytoplankton and meiofauna constitute the food sources for *secondary productivity,* organisms such as zooplankton that in turn are eaten by shrimp.

Importance of Natural Productivity such as Plankton in Ponds

Much emphasis is placed on stimulating primary productivity in shrimp culture. While primary productivity alone is not sufficient to support good shrimp growth except under very low density conditions, it makes important contributions to both the quality of the shrimps' diet and towards reducing the amount of expensive pelleted feed required. The duration of the grow-out cycle can also be reduced when nutritional requirements are met in this way.

Plankton is most important in extensive systems where little, if any, additional feed is added. Semi-intensive systems rely partially on primary productivity to meet shrimp nutritional needs while in intensive culture, it may play an insignificant role.

Plankton provides the essential micronutrients missing in many commercial shrimp feeds. In the absence of dietary input from natural productivity the commercial shrimp feed used must be complete, or growth will be poor. Newly stocked larvae generally favor natural foods over crumbled feeds. If the newly stocked pond is deficient in plankton, the larval survival can be at risk. Fertilization prior to stocking is therefore important.

Phytoplankton also plays an important role in regulating water quality parameters. Algae are natural biofilters, and very effective removers of soluble nitrogenous waste products like ammonia. Phytoplankton and suspended solids shade the water column, creating a more favorable environment for the shrimp, which generally dislike strong light. The most economical way to aerate or oxygenate pond water is through algal photosynthesis.

The type of plankton that is present in a pond is important. Diatoms are preferred for their superior nutritional content. Some algae possess natural antibacterial properties. Blue-greens and dinoflagellates are considered undesirable because they may cause unstable water chemistry and health problems in shrimp (hemocytic enteritis, growth inhibition), and blue-green algae can be responsible for off-flavor in shrimp. *Gleosystus* major is suspected of causing problems in ponds in Texas. It has an envelope that carries bacteria, and is thought to infect shrimp, but more research is needed to find the exact mechanism of infection.

Some blue green algae have slower growth rates than other algae so flushing a pond can help lower the numbers of blue greens which might allow the faster-growing green algae to become dominant. There is some thought that the ratio of N:P is important and the N level must be high to help control the blue greens.

The presence of zooplankton (mainly copepods, cladocerans and rotifers) is beneficial. The presence of ciliated protozoans is a negative indicator since it may be indicative of high organic levels.

Table 1 gives an example of what may be considered an example of a diverse and beneficial plankton community. Phytoplankton community composition will vary widely.

Table 1. Optimal plankton densities in shrimp ponds (Clifford, personal communication 2000).

	Cells/ml	
Type	**Minimum**	**Maximum**
Diatoms	20,000	
Chlorophytes	50,000	
Blue-green algae	10,000	40,000
Dinoflagellates	-	500
Total algae	80,000	300,000
Zooplankton	2	50
Ciliates	10	150

Algal Growth Dynamics

The growth of algae can be expressed in terms of plant cell division. With adequate nutrients in pond water, and proper light and temperature, algal populations will grow exponentially. A summary explanation of algal population dynamics follows. The first phase is known as the lag phase (phase 1, Figure1). This period of initially slow growth is not completely understood but could possibly be attributed to algal cell size increase without cell division. The second is the exponential phase, during which the cells divide rapidly. The third phase is characterized by the decline of growth and occurs concomitantly with the depletion of a particular nutrient. The fourth stage is the stationary phase, when the rate of algal growth is balanced with the limited nutrients in the water. The final stage is the death of the culture, usually due to extreme levels of nutrient depletion (Figure 1). Although the latter seldom occurs in pond systems, pond fertilization attempts to maintain the algae in the growth phases and to avoid nutrient depletion that would lead to poor algal growth or death.

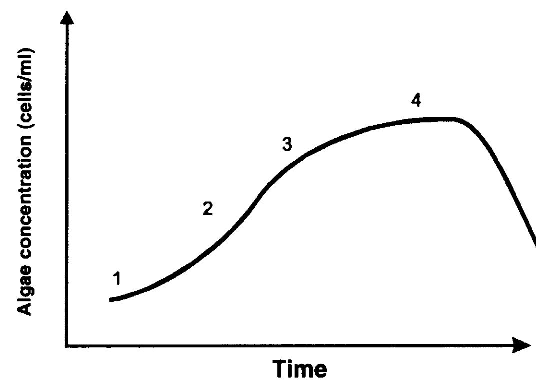

Figure 1
The growth phases of algae.
Source: Villalon 1994, modified by Fox 1994.

FERTILIZATION PROCEDURES

General Fertilization Strategies

A fertilization regime ideally should promote a beneficial algal bloom using the least expensive type(s) of fertilizer that does not produce detrimental effects on either pond dynamics or the environment.

Good pond managers often try to identify and quantify the plankton in their ponds based on the idea that certain types of algae, in particular diatoms, are the most beneficial. Identifying algae species and determining abundance is time consuming and technically exacting. There is some debate as to whether the usefulness of the resulting information justifies the expense. Many farmers like to know what they have in their pond water and so will conduct these tests, but this is most likely not necessary.

It is generally agreed that a good algae bloom must be established before stocking since small shrimp preferentially consume phytoplankton and zooplankton. The primary productivity must be maintained over the growth cycle. It is also a recommended practice that the density of the bloom be monitored over the growth cycle using a Secchi disc (see Chapter 2) and algal counts. The decision to apply fertilizers and the dosage should be based on the use of these simple tools. Careful monitoring reduces the cost of fertilization, helps maintain optimal levels of algae and prevents water quality problems due to over-fertilization.

Fertilization is usually on-going during the grow out cycle because it helps to replace nutrients and food organisms flushed out of the pond during routine water exchange and when the pond is drained at harvest. Feed also acts as a fertilizer and once feeding starts, less fertilizer is needed. As many farmers move towards reducing or eliminating water exchange, fertilization rates are reduced.

Organic fertilizers can be beneficial for pond preparation because they offer a self-contained microbial population and detrital substrate for their development. Organic fertilizers most commonly used in shrimp ponds are manures (chicken, cattle, swine, duck), rice bran, cottonseed meal, sugarcane processing wastes, burnt rice hulls, and bermuda grass pellets.

Organic fertilizers provide a gradual release of nutrients from the activity of heterotrophic and chemotrophic bacteria and can be consumed directly by newly stocked larvae (Clifford 1992). Manures in general are characterized by high C:N ratios, and do not decompose quickly (Boyd 1989). Table 2 shows the rate of biodegradation of organic fertilizers and the ultimate BOD load on the pond or water column.

Table 2. Organic Fertilizers and biodegradation and BOD in ponds. Clifford (personal communication, 2000).

Organic fertilizer	Rate of biodegradation (K*)	Final BOD (mgO_2/L)
Chicken manure	0.27	412
Wheat bran / Middlings	0.20	1426
Cottonseed meal	0.18	1143
Alfalfa meal	0.17	1255

*K is a rate function. In this case it represents the rate of biodegradation by bacteria over time (for example grams of organic matter decomposed in 24 hours).

From the information above one can see that chicken manure breaks down more rapidly than alfalfa, and alfalfa adds more BOD to the water. It is also observed that organic fertilizers contribute heavily to the BOD load of a pond.

It is generally recommended that manures not be used because they cause degradation of soil and water quality and manures from some sources may have high concentrations of heavy metals and antibiotics. Use of manures may introduce pathogenic bacteria that may later prevent sale of the shrimp (Chapter 8). Also, many consumers would not like to purchase shrimp from manured ponds.

Pond Preparation Before Initial Fertilization

Prior to filling the pond and fertilizing, some preparatory steps are necessary. Pond preparation influences the reaction of an individual pond to fertilization. Good pond preparation is equally important as pond management during the grow-out cycle. It is imperative to dry the pond for a minimum of 7 to 10 days. Lime should be applied according to the guidelines given in Chapter 10 and below. Many ponds have areas which do not dry easily, especially during the rainy season. These areas harbor fish and other organisms which must be eliminated before stocking. In some cases, the use of itiocides may be required.

Application of agricultural limestone is required when pH in soil is low to ensure good fertilization response. Recommended application rates are:

For soil pH <5, apply 3,000 kg lime /ha
For soil pH 5-6, apply 2,000 kg lime/ha
For soil pH 6-7, apply 1,000 kg lime/ha.

If predator fish or other organisms need to be eliminated use one of the following to treat:

Rotenone 1-4 mg/L
Calcium hydroxide 100-200 mg/L
Calcium oxide 50-100 mg/L
Malathion 2-4 mg/L
Teaseed 20-35 mg/L.

The use of teaseed is preferred over chemical agents such as malathion since it is a natural substance. Use if chemicals not approved for use in producing food products shrimp importing countries is not recommended.

Caution should be taken that these substances be:

- used according to manufacturers' instructions;
- used only in limited areas and when absolutely necessary;
- sufficient time should be allowed for all products to degrade to avoid contaminating larger water bodies; and
- personnel applying these substances should be trained in proper handling and appropriate protective gear worn.

Fertilizer Application

The first principle of effective fertilizer application is to dissolve the fertilizers before or while they are being dispersed. Granular forms of inorganic fertilizers may chemically bind to components at the mud bottom and reduce the effectiveness of nutrient enrichment of the water column.

There are two procedures for proper fertilizer dispersal:

1) dissolve fertilizers in a tank of water before applying to the pond. Once dissolved, the liquid is dispersed over the entire surface of the pond by personnel in a boat. A metered holding tank can also be placed at the entrance gate so that the nutrient solution gradually drips into the water; or

2) solid fertilizer is placed in an empty feed bag or a fertilization cage at the entrance gate, thus allowing the water current to dissolve it .

This second alternative should only be implemented when the entrance gate is oriented upwind in relation to the longitudinal axis of the pond, since the wind facilitates uniform dispersal. If the entrance gate is not oriented upwind, one alternative to ensure uniform dispersal is the use of fertilization cages or empty feed bags attached to the side of a boat. The cages or feed bags should not drag on the pond bottom and the boats should carefully and uniformly cover the entire pond surface area.

Fertilizer types and dosage

Response to a fertilization regime varies between individual ponds since it is influenced by soil and water quality. The criteria for dosage application aim to ensure the presence of the following nutrient concentrations in pond water:

1) Nitrogen 1.3 ppm; and
2) Phosphorous 0.15 ppm.

Although levels of these two primary nutrients undoubtedly vary from farm to farm, and between different ponds on the same farm, experience indicates that an approximation may be effective for most facilities. Not all farms are able to conduct water analyses, so another general rule of thumb is that an application of 9 kg of urea and 0.9 kg/ha triple superphosphate a good starting point for a fertilization regime (see Chapter 1).

Other initial fertilization programs can be as high as 60 kg/ha urea and 3 kg/ha TSP, N:P = 46:1 and 1000 kg/ha chicken manure. An alternate fertilization program might be 60 kg/ha sodium nitrate, 3 kg/ha diammonium phosphate, 20 liters/ha sodium metasilicate, and 1000 kg/ha chicken manure. With a high initial fertilization program such as this, a maintenance fertilizer program might be 23 kg/ha urea and 2.3 kg/ha TSP, N:P =22:1. The maintenance program requirements will depend upon local conditions. See Table 3 for examples of fertilization regimes.

Table 3. Fertilization regimes utilized in shrimp pounds.

Country	Fertilizers (kg/ha)	N:P	Source
Colombia	U(15) + DAP (4)	9:1	Clifford (unpubl.)
Ecuador	U(9-23) + TSP (0.9-23)	9:1	Villalon (1991)
Ecuador (P)	U(16) + TSP (8)	4:1	Hirono (1989)
Ecuador	U(8-12) + TSP (4-6)	4:1	Hirono (1989)
Ecuador (E)	U(20) + TSP (7)	6:1	Figueroa (1991)
Ecuador (P)	U(22) + TSP (6)	8:1	Figueroa (1991)
Ecuador	U(5.6) + TSP (2.2)	6:1	Figueroa (1991)
Ecuador	U(15-30) + FTC (8.3-17)	45:1	Wigglesworth (1991)
Indonesia (P)	U(100) + TSP (50-100)	2-4:1	Chamberlain (1991)
Indonesia (P)	U(150) + TSP (75)	3:1	Ahmad (1989)
Indonesia	U(25) + TSP (10)	6:1	Ahmad (1989)
Mexico (P)	U(15-35) + TSP (5-12)	7:1	Figueroa (1991)
Panama	U(20) + TSP (15)	3:1	DNA (1984)
Philipp. (E.P)	U(50) + AP (50)(*)	7:1	Apud (1989)
Philipp. (E)	U(7) + DAP (65)	1:1	Subosa & Bautista
U.S.A. (P)	U(25) + TSP (15)	4:1	Jaenike (1989)
U.S.A.	U(45)		Figueroa (1991)
Universal	-	20-30:1	ASEAN (1978)
Universal (P)	U(7.9) + TSP (2.6)	7:1	Cook (1991)
Universal	U(2.5) + TSP (0.5)	11:1	Cook (1991)
Not specified	U + TSP	15-30:1	Boyd (1989)

Key to abbreviations: **(P)**= Pond preparation, **(E)** = Extensive pond, **N:P** = Nitrogen: phosphorus, **U** = Urea, **TSP** = Triple superphospate, **DAP** = Diammonium phosphate, **AP** = Ammonium phosphate (16-20-0), **FTC** =" Ferticam" (37-6-3) (Clifford 1992).

* supplemented with 2-3 tons of chicken manure.

If these guidelines prove ineffective, adjustments should be made until the correct dosage has been obtained for each situation. Likewise, because nutrient requirements change in relation to climatic conditions and seasons, most fertilization programs are dynamic and susceptible to change.

Initial Fertilization Regimes

Postlarvae or juveniles often experience stress during stocking. Postlarvae have generally gone through an acclimation period where they are confined at densities of 500-1000 larvae/liter or for a prolonged time of 24 hours in densities of less than 500/liter. It is therefore important that once the animal has been stocked in the pond, it does not undergo additional stress or weakening due to insufficient food. Proper pond preparation and a conscientious fertilization program are designed to maximize primary productivity in prestocked ponds.

Pond preparation and initial fertilization are time-consuming and costly in terms of resources expended and production time lost. The disinfection/pond preparation stage may take up to 16 days while the initial fertilization regimes described below require 14 days. This represents a substantial loss of production time. Although investing the time and money to properly prepare a pond for stocking will yield significantly improved production to justify these expenditures, efforts to minimize "down-time" should be made through an aggressive and efficient program of preparation carried out by trained and competent personnel.

Two methods of initial fertilization regimes to prepare ponds for stocking are presented here. Before beginning the initial fertilization, it is important to follow guidelines for pond disinfection and preparation presented in Chapter 10.

Farms that use feeding trays often have insufficient amounts of organic material on the pond bottom to promote good zooplankton growth for the next crop. The Peruvians developed a method of pond bottom fertilization between crops that helps promote excellent zooplankton populations. When the pond bottom is dry they till old shrimp feed or inexpensive shrimp feed into the soil as well as fatted soy bean. Large numbers of zooplankton, mainly copepods, cladocerans and rotifers, can be seen only a few days after the pond is filled.

Start-up procedures are as follows. The procedures are presented as examples that must be modified according to individual farm and pond needs.

Initial fertilization-Method 1

1) Water added should fill the pond in preparation to cover the majority of the surface area (>60%) to a 10-30 cm depth.

2) While the pond is being filled, it should be fertilized with 9 kg of urea and 0.9 kg of triple superphosphate per hectare of total pond surface area. The water should be filtered to exclude predators and disease vectors. Inlet water filtration is accomplished with 0.5 mm or 500 micrometers screens and outlet filtration is accomplished with 1mm screens before stocking. If WSSV (whitespot) is present, then 2 cm mesh screens are placed at pump station; 1-2 mm screens are placed at lateral branches of supply canal; inlet structures should have a 500 micrometers screen, followed by 200-300 micrometers screen; then 2-3 cm mesh screens are placed in drainage canals.

3) Water exchange should then be stopped and the water allowed to stand for approximately 2-3 days until the water color becomes dark brown with a yellowish hue.

4) After 2-3 days, the water level is increased until it reaches 50% of its operational level. While the pond is filling, 14 kg of urea and 1.4 kg of triple superphosphate should be applied per hectare, ensuring that it is adequately dispersed over the pond surface area.

5) After the second application of fertilizer, the pond should again be allowed to remain for 2-3 days without adding water. If, after the third day, the water has not turned dark brown with a yellowish hue in color, then 92 kg per hectare of calcium carbonate should be applied. The slight increase in pH may help stimulate the proper bloom.

6) Once the water has turned dark brown with a yellowish hue, the pond should be filled to the water level used for production.

7) As water is added in the final filling stage, at last application of fertilizer should be made at a dosage of 23 kg of urea and 2.3 kg of triple phosphate per hectare.

8) Once the pond reaches the desired water level, no further water should be added for 5 days. At this time the pond is on "stand-by", but ideally it should not be stocked with juveniles or postlarvae until it has been allowed to "age" for this length of time. Secchi disk readings of 25 - 35 cm water of a yellowish - brown color will confirm that optimal conditions exist for best stocking results. Table 4 shows zooplankton generation cycles (egg to egg time requirements in ponds) and ages (in days) of zooplankton at maximum fecundity.

Table 4. Zooplankton Cycle Times and Ages at Maximum Fecundity (Clifford, personal communication 2000).

Zooplankton	Egg to egg cycle time (days)	Age at maximum fecundity (days)
Cladocerans	7	14-15
Copepods	14	24
Rotifers	2-3	3-4

9) If after the fifth day, color of the water and the Secchi disk reading have not reached the optimal, the water level should be dropped by 10 cm and additional fertilizer added. This should be done with 6.8 kg of urea and 0.7 kg triple superphosphate per hectare.

When ponds are in the "stand-by" condition during the rainy season, it may be necessary to partially drain the pond to maintain optimal salinity. This can be achieved by adjusting the boards in the drain structure so that the upper layer of water is removed. This helps maintain a higher salinity since rainwater has a specific gravity lower than saline water and therefore will have tendency to remain on the surface of the pond. **Caution:** This should only to be performed in ponds not yet stocked; care should be taken when draining surface water of stocked ponds that shrimp do not escape. As a general rule when exchanging water, always drain water from the bottom of the pond unless there is a heavy rain or there is a localized bloom of dinoflagellates that need to be drained from the surface of the pond. Generally the poorly oxygenated water is located at the bottom and should be removed.

Initial Fertilization-Method 2

Some of the best fertilizers to use are diammonium phosphate (DAP) 17-46-0 in granular form, triple superphosphate (TSP) 0-46-0, ammonium nitrate (AM) 33.5-0-0, urea 46-0-0, sodium nitrate 16-0-0, and molasses. The ratio of urea to DAP/TSP used in pond fertilization may vary from 5:1 to 10:1 (or higher) depending on pond nutrient level and the quality of the incoming reservoir water. The manager should determine the proper ratio based on response to the fertilizer and on past experience. Either method (i) or (ii), described below, may be used for initial fertilization, depending upon the requirements of the water.

(i) Before filling ponds, apply 44.6 kg/ha DAP or TSP, and 44.6 kg/ha of urea over dry pond bottoms. Spread fertilizer as uniformly as possible. To increase substrate area in some ponds, 446 to 893 kg/ha of rice processing water, or 223 kg/ha bagasse may be applied to the pond bottom. The bagasse needs to be soaked a few days in pond water while the pond is filling, then spread over the pond surface. While the pond is filling, add 37 to 47 liters/ha of molasses at the inlet. Fill the pond until 60 to 70% of the bottom is covered, and hold for a couple days or until a bloom develops. At this point, a Secchi disk reading of 25-30 cm is desirable. Continue filling the pond to stocking level of 30 cm below full, applying routine fertilization daily or as required.

(ii) Initial fertilization begins the day after step 2 of pond filling begins (see above, Initial Fertilization-Method 1). Fill the pond to cover at least 60% of the bottom. While the pond is being filled, fertilize with 9 kg of urea with either 0.9 kg of DAP or 1.8 kg of TSP per hectare of total pond surface area at the inlets so water can gradually dissolve the fertilizer.

(iii)When the water is deep enough, spread urea by hand directly from a boat. The fertilize is dissolved in a container and slowly poured into the water in front of an outboard engin on a moving boat so that the propeller mixes the fertilizer. After one day, begin bringin level up to 50% of pond volume. While filling, add 13.6 kg of urea and either 1.3 kg of DAI or 2.7 kg of TSP per ha, ensuring adequate distribution over the pond surface area.

(iv)Skip another day. Continue to fill pond to 5 cm below the maximum operative level While filling, add 22.6 kg of urea and either 2.2 kg of DAP or 4.5 kg of TSP per ha.

(v)Additional fertilizer may be applied if a bloom has not developed before the stockin date. Ammonia levels must be checked daily preceding stocking to an acceptable level fc postlarvae. Ammonia levels can be reduced by flushing if they are unacceptably high.

Fertilizer may be applied at reduced levels immediately before and after stocking to prevent excessive ammonia levels.

Whenever the morning Secchi disc reading is greater than 35 cm, routine fertilization will be applied a minimum of two times per week.

In the first few weeks of pond culture it may be necessary to initially fertilize on consecutive days, then every other day. Eventually bi-weekly routine fertilization should be enough to maintain turbidities of 35 to 40 cm.

When the turbidity reading is less than 30 cm, suspend fertilization until turbidity decreases to greater than 35 cm.

If turbidity readings are less than 20 cm, suspend routine fertilization and the daily feed ration, and increase water exchange rate by 20%, flushing until turbidity readings are greater than 35 cm.

Routine fertilization during grow-out

There are several means of assessing and monitoring algae blooms during grow-out. Conventional laboratory measurements of phytoplankton productivity, or biomass, still are not available to many farms. Farms with laboratory equipment can measure chlorophyll-*a* directly and indirectly calculate algal cell densities. Use of the Secchi disk provides an estimate of water turbidity generally related to plankton abundance. An experienced observer can readily distinguish between turbidity due to plankton and that due to other factors. Plankton blooms do not always cause water to appear green or golden brown for such blooms may also impart yellow, red, brown or black coloration to water. It is important to use the Secchi disk carefully to ensure accuracy (see Chapter 1).

Different observers using the same technique may obtain different readings; therefore, analyses made by the same person may reduce variations and be more useful for comparison between ponds. Measurements taken at various times of day by the same observer may differ appreciably because of differences in light reflection and turbulence at the water surface. For these reasons, it is important that one person be designated for this daily task. The Secchi disk measurement should be taken on platforms extending into the pond near the effluent gate. Measurements should be taken daily at the same hour.

In order to establish an economically feasible fertilization program, knowledge of individual pond characteristics such as weekly soil and water nutrient levels is necessary. Because such data are generally not available for all ponds, fertilization schedules must be tested under the varying conditions found on a farm. Careful monitoring and continuous adaptation of the regime based on monitoring results will allow a prescribed fertilization schedule to be modified to suit specific conditions.

Monitoring the results of fertilizing is governed by Secchi disk measurements. When Secchi disk readings are above 30 cm, a routine fertilization dosage of 1.8 kg of urea and 0.2 kg of triple superphosphate per hectare of surface area every three days should suffice.

If Secchi disk readings fall between 25 and 30 cm, the routine fertilization program for that particular pond is temporarily suspended until transparencies increase to above 30 cm. If transparencies decrease below 25 cm, fertilization should be temporarily suspended along with the daily feed ration. Water exchange rates should be increased by 25% to flush out a portion of the algal bloom. This procedure should be maintained until transparencies have increased to 30 cm or above.

Maximizing the residence time of the fertilizer within the system during the routine fertilization program (every three days) allows for more effective use of the fertilizer. To accomplish this, pond water levels are reduced by 10 to 15 cm the day before the programmed fertilization begins. As the pond fills and regains its operative water level, nutrients from the fertilizer are not immediately flushed out.

Based on the dosage and the schedule of this fertilization regime, it is calculated that fertilization accounts for roughly 0.5 to 2.0% of total production cost per pound of harvested shrimp.

One important consideration in pond fertilization is the ratio of nitrogen to phosphorus (N: P). Many pond managers believe that a high N:P ratio promotes beneficial diatoms and algae (not blue greens), especially during higher salinities in the dry season, although there is no replicated scientific studies to support this. To achieve this purported benefit, many recommend that a 5:1 N:P or higher ratio be used. A higher ratio is preferred and is optimal at 10:1 to 20:1 according to most pond managers who subscribe to this practice. This ratio describes the weight of each component used, not the relative percentages of nitrogen and phosphorus.

An initial fertilization regime which works in Nicaragua at some farms is 10 to 15 kg/ha of Nutrilake (trade name) and 3 to 3.3 kg/ha of TSP applied twice weekly initially, then progressively less over time. A second regime which works better at some farms is 50 to 150 kg of Nutrilake mixed into the pond bottom initially, with less being applied over time.

The source of nitrogen is important, but not as important as the quantity ratio with phosphorus. If Nutrilake works better than urea, then it should be used. Nutrilake also has silicate which may help diatoms in test shell (formation).

The cost of fertilizer is far below the cost of postlarvae and feed. The manager's time is best spent trying to economize on feed and postlarvae more than on fertilizers. Use what works best, and shrimp growth rates should make up the difference in any added costs of nitrogen. Table 2 illustrates a typical routine fertilization regime.

If a phytoplankton bloom crash causes low DO levels, emergency fertilization should be implemented by adding 6.8 kg of urea and either 0.67 kg of DAP or 1.36 kg of TSP per hectare of pond surface area.

ROUTINE FERTILIZATION (1 lb = 0.45 kg; 1 Gallon = 3.79 Liters)

Table 5. Example of Routine Fertilization of 27, 20-ac. ponds[1] .
Source: Villalon 1991.

Pond	Urea (lb)	DAP (lb)	Molasses (gal)	Pond	Urea (lb)	DAP (lb)
1	50	5 (or 10)	15	14	40	4 (or 8)
2	50	5 (or 10)	15	15	40	4 (or 8)
3	50	5 (or 10)	15	16	40	4 (or 8)
4	20	2 (or 4)	5	17	40	4 (or 8)
5	40	4 (or 8)	10	18	40	4 (or 8)
6	40	4 (or 8)	10	19	40	4 (or 8)
7	40	4 (or 8)	10	20	40	4 (or 8)
8	40	4 (or 8)	10	21	40	4 (or 8)
9	40	4 (or 8)	10	22	40	4 (or 8)
10	40	4 (or 8)	10	23	40	4 (or 8)
11	40	4 (or 8)	10	24	40	4 (or 8)
12	40	4 (or 8)	10	25	40	4 (or 8)
13	40	4 (or 8)	10	26	10	1 (or 2)
				27	10	1 (or 2)

See Chapters 1 and 10 for additional information on fertilization of ponds.

1 Multiply pounds of urea by 1.5 if ammonium nitrate is substituted and multiply by 3 if sodium nitrate is substituted.

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6 POSTLARVAE ACCLIMATION AND STOCKING

POSTLARVAE ACCLIMATION AND STOCKING

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Introduction

Acclimation is the process of gradual physiological adjustment of postlarvae from the hatchery conditions to those of the ponds in which they will be stocked. The most important variables to which shrimp are acclimated are salinity and temperature, although other water quality values must sometimes be considered. Avoidance of stress and of rapid environmental changes are key to successful acclimation and improvement of survival.

Emphasis is placed on proper acclimation procedures since the cost of postlarvae represents a significant percentage of the cost of producing shrimp. The postlarval stage is the most sensitive life stage of shrimp and requires careful handling and management to prevent high mortalities and impaired growth. A good understanding of stocking and acclimation procedures can significantly improve the economic returns of an operation. Conservation of other inputs and resources is also enhanced with the best use of postlarvae.

Sources of Postlarvae

Wild caught postlarvae are sometimes used for stocking ponds. Wild postlarvae have the advantage of being locally available in some places. They also represent a source of income for local residents. However, use of wild postlarvae entails many potential problems. Among these are the multi-species composition of the catch, wide fluctuations in abundance, and decreasing populations because of habitat destruction.

Hatchery produced postlarvae should be used where possible to stock ponds. The shrimp industry is rapidly moving to nearly complete dependence on hatchery produced larvae as this tends to ensure a more regular supply, avoids any possible issues related to fisheries management of the postlarval stock and guarantees obtaining only the target species. Additional benefits include being able to selectively breed shrimp. Because disease is among the foremost threats to the industry, procurement of Specific Pathogen Resistant (SPR), Specific Pathogen Free (SPF), or High Health Genetically Improved (HHGI) organisms for stocking is highly advantageous (see Chapter 7).

It is recommended that the native species of shrimp or species which are already being grown in the area be preferred to avoid the introduction of exotic species. In the case of Latin America, the principal native and cultured species are *Litopenaeus vannamei* and

Litopenaeus stylirostris, although other minor Penaeid species are encountered in culture when wild postlarvae are used.

When purchasing postlarvae, the rule of thumb is "buyer beware". Two key issues are presented. First, the overall health and quality of postlarvae are key to success and buyers must take the responsibility themselves to assure that the condition is satisfactory. It is generally a good idea for the buyer or a representative to inspect the postlarvae before shipment, accompany the shipment and monitor the survival of the animals after stocking. This person should also measure and report on water quality parameters in the hatchery to the acclimation facility so that the water reservoirs can be prepared.

There are various means of assessing the condition of postlarvae and for monitoring their survival after stocking. These are detailed in Villalon (1994).

The health status of postlarvae is also of concern. If postlarvae are sold as SPR, SPF or HGGI this status must be certified by the appropriate authority. Evidence of certification should be kept on record by the buyer and seller. Buyers may also wish to independently verify that the postlarvae do not exhibit signs of disease whether they are SPR, SPF, HGGI or without such status. Details regarding diagnostic methods are described in Chapter 7. Personnel executing diagnostic procedures must be well trained and equipped if the results are to be useful.

Acclimation Facilities

On a large farm, acclimation should be done at a central location as opposed to the pond site. Facilities should provide shade, air, filtered water and easy access.

Postlarvae can be acclimated in a variety of structures as long as water and air can be provided and hygienic conditions can be maintained. Fiberglass rectangular raceways have worked well at the Nova farm in Belize for this purpose. When the raceways are not being used to acclimate larvae they are put to good use growing beneficial algae and diatoms, which are used to seed the reservoir and ponds.

Tank capacity and number for an acclimation facility should be based on the routine stocking needs of the farm. Recommended stocking densities for acclimation and stocking activities are 500 postlarvae per liter (Villalon 1991). Maximum capacity is 100,000 ton tanks although 50,000 to 75,000 ton tanks are preferred. If the facility is to be used to acclimate larvae only, stocking densities can be kept at 500 to 1,000 shrimp per liter during acclimation, but if prolonged holding is necessary (greater than 24 hours) then stocking densities should be held below 500/liter. Some farms hold larvae at 75 postlarvae/liter; however, research and commercial trials have shown that larvae can be stocked at much higher stocking densities which will be discussed later. These suggested stocking rates are size-age dependent and must be adjusted over long holding periods.

Postlarvae Acclimation Procedures

Opening transport bags upon arrival from hatchery

Open each bag containing postlarvae and immediately measure and record the temperature and oxygen concentration. Visually evaluate the condition of each bag. Smell the water, observe activity, number of mortalities. If mortalities are seen in transport bags, estimate the percent mortality. Note if mass mortalities have occurred.

If oxygen is below saturation (<15 mg/l) immediately bubble oxygen into the transport bag until oxygen is at saturation or a minimum reading of 12 mg/l. Oxygen saturation depends directly on temperature and salinity.

Preparing acclimation tanks

The entire acclimation facility should be thoroughly cleaned several days before postlarvae are to be received. This entails soaking all tanks, surfaces and plumbing using a hypochlorite solution [1] for at least one hour. These should also be scrubbed with this solution. A thorough rinsing with clean water follows, after which everything should be left to dry. Care must be taken to eliminate all residue of hypochlorite before postlarvae are brought into the facility. Equally important is to avoid using hypochlorite in any water containing ammonia since this can release toxic chlorine gas.

The reservoir tank should be filled with water from the pond to be stocked. Most facilities filter acclimation reservoir water to 0.5 mm or 500 micrometers. Some filter as much as 125 micrometers. EDTA should be added to each tank to reach a concentration of 2 ppm.

Pond water must be cooled before adding the postlarvae. Do not add warm pond water directly to acclimation tanks. Place about 200 liters of pond water in an auxiliary tank and use ice in plastic bags to cool water to 26 to 27 °C. The cooled water then adjusts the temperature in acclimation tanks until it reaches 25 °C.

Measure the pond water temperature, pH, oxygen, salinity, and ammonia level and record on an acclimation record sheet.

Measure acclimation tank water temperature, pH, oxygen, salinity and ammonia level and record on the acclimation record sheet (Appendix 1).

Measure the average temperature and oxygen levels in all plastic bags and record on acclimation record sheet.

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[1] Dry chlorine mixtures are calcium or sodium hypochlorite. For disinfecting purposes, a concentration of 12-25 ppm is recommended. To make a concentration of approximately this concentration, add 115-168 g dry chlorine mixture (the amount of free chlorine varies) to 500 gallons clean water. Use this solution promptly. If liquid house hold or swimming pool bleach is used, a 2.5 ppm concentration is recommended and is obtained by mixing ½ ml per liter of clean water. Liquid formulations have more free chlorine available and are more stable over time.

Postlarvae stage	Stocking density (postlarvae/ ft^2 of tank bottom area)
5/6	2,323
7/8	2,044
9/11	1,765
12/15	1,208

The water in the acclimation tanks should be adjusted to the average salinity in the transport bags. Temperature should be also adjusted.

Recommended Densities for Acclimation Tanks According to the Age of the Postlarvae

Maximum stocking densities in the acclimation tanks are: (number of postlarvae/ft^2 of tank bottom area).

An example from industry is the Nova Farm (Belize) which found that the ideal acclimation density for postlarvae older than 12 days was 179,404 postlarvae/m^3. This result was based on stocking needs. This density gave best survival while these volumes took the least amount of time to complete the acclimation procedure and get the shrimp in the ponds.

Typically, a stocking density of around 140,000-150,000 postlarvae/m^3 should be possible, but this is site-specific.

The acclimation facility may need more than just primary filtration if postlarvae are to be held longer than the acclimation period. For example, if postlarvae were to be held an additional 4 to 10 days for quarantine purposes additional measures would be necessary to maintain adequate water quality. In this case, a recirculation system with biological filtration and UV disinfection may be necessary to keep survival high.

Postlarvae Transfer to Acclimation Tanks

On very hot days place a plastic bag with ice on each tank bottom for a few minutes to cool the tank before stocking postlarvae in the tank. The temperature should be 25 °C.

Start bubbling oxygen lightly through water to reduce ammonia levels as soon as the postlarvae are transferred.

Scatter approximately 50 g of activated carbon pellets in each tank. Adjust this amount for different tank sizes.

After all transport bags have been placed in acclimation tanks, make a "clinical" evaluation of the postlarvae. Use a 500 - 1000 ml glass or transparent plastic beaker to collect samples from each acclimation tank.

Note and record on postlarvae evaluation sheet activity (Appendix 1) gut fullness, signs of molting, signs of cannibalism, presence of dead shrimp, and opaqueness of color on tails. Complete details on assessing physiological condition are given in Villalon (1994).

Check temperature, oxygen and salinity every 30 minutes, and pH and ammonia every hour. Record the results on the Postlarvae Acclimation Sheet.

Volumetric Counts

Once the postlarvas have been stocked in the acclimation tanks, take random samples of 20 to 30 animals and send to the laboratory for microscopic evaluation. The laboratory personnel should conduct the volumetric counts and estimates of mortality.

If significant mortality is observed in a shipment of postlarvae, the Quality Control Manager will estimate the total number of live postlarvae in acclimation based on the estimate of mortality. This count has to be done before any pond water is added to the acclimation tanks. Once the count has been conducted, the acclimation tanks can be filled.

Oxygen Levels

Oxygen should be added during acclimation as follows:

During the first hours of acclimation ammonia levels are high. Oxygen levels are to be maintained above saturation (12 mg/l - 15 mg/l). Note that oxygen saturation depends on the water temperature.

Optimum oxygen levels throughout acclimation are to be maintained at 8 mg/l - 12 mg/l.

Oxygen levels should not go below 6 mg/l at any time during acclimation.

Oxygen levels should be raised to 10 mg/l in the acclimation tanks just prior to stocking to compensate for the travel time.

Acclimation Procedure and Schedule for Postlarvae 5 to 11

The objective of acclimation is to slowly adjust the temperature and salinity of the acclimation tanks so that the postlarvae have an opportunity to make physiological adjustments to new conditions.

Acclimation should begin immediately upon emptying the last transport bag into the tanks. Water from the reservoir tanks is then slowly added using a flow through system so that volume in the tank remains the same. The change in salinity should be carefully monitored and the rate of change should not exceed that given in the table below.

Recommended rates of salinity increase for acclimation

Salinity (ppt)	Rate of salinity increase (ppt/min)	Rate of salinity increase (ppt/hour)
34-25	1 ppt/30 min	2 ppt/hour
25-20	1 ppt/30 min	2 ppt/hour
20-15	1 ppt/30 min	2 ppt/hour
15-10	1 ppt/40 min	
10-5	1 ppt/45 min	
5-0	1 ppt/60 min	

For temperature acclimation the recommended rate of change is 1 °C per hour, but healthy larvae can be subjected to a rate of 1 °C per 10 minutes. A good strategy is to maintain temperature constant at 25 °C for the first 75% of the acclimation period (while salinity is being adjusted) and then slowly adjust the temperature towards the end of the acclimation period. Maintaining the temperature constant reduces aggressiveness and keeps metabolic rate relatively slow.

The acclimation schedules discussed above are merely guides, and the rate of acclimation should be diminished if the larvae demonstrate signs of increased molting or stress. Careful monitoring is required. Whitish or opaque coloration, erratic swimming behavior, empty guts, or increased cannibalism are all indications of stress. Generally larvae will come to the surface if stressed.

It is recommended that once acclimation is completed, postlarvae be put into the ponds as soon as possible unless quarantine is the goal. Holding larvae at high densities after acclimation can lead to problems with poor water quality, stress, mortality and disease.

If postlarvae need to be held after acclimation is completed, it will be necessary to filter and disinfect the water with either UV and/or ozone. The local water quality must also be considered. It is easier to hold postlarvae in water from an oceanic source rather than an estuary source since the water quality is generally better.

Further review of the literature by Clifford (1994) indicates the ideal holding densities for acclimation and transport of post-larvae are as follows:

Activity		Pl size/age	Reduce temp.	density (Pl/liter)	per ton
Transport, insulated box		12	Yes	1000-2000	1-2 million
Transport, insulated box		13-18	Yes	500-1000	500,000-1 m
Acclimation(1-2 hours)		8-12	No	750-1000	750,000-1 m.
"	(3-6 hours)	8-12	No	500-750	500,000-750K
"	(>6 hours)	8-12	No	300-500	300K-500K
"	(1-2 hours)	13-18	No	600-800	600K-800K
"	(3-6 hours)	13-18	No	400-600	400K-600k
"	(>6 hours)	13-18	No	250-400	250K-400K
Transport(hatchery to pond)		8-12	No	750-1000	750K-1 m.
" "	"	13-18	No	500-750	500K-750K

Feeding Techniques in Acclimation or Postlarval Holding Facilities

A good feeding regime to accompany acclimation is important so that postlarvae will have sufficient energy to combat stress caused by changing environmental conditions. Feeding may begin when acclimation is initiated as long as the volumetric counts have been completed.

Feeding during acclimation

Villalon (1991) suggests *Artemia* nauplii, egg yolk (boiled), a commercial flake diet and frozen *Artemia* be supplied as feed to acclimation tanks.

Feeding during holding

Samocha et. al (1993) used stocking densities of 500 to 1000 postlarvae per liter (500,000-1,000,000 per ton of water) only during the acclimation process. Following this, a stocking density of 3,200 postlarvae/m^2 was used for holding in the raceway, with up to 90% survival after holding for 5 weeks. They tested stocking densities up to 7,800 postlarvae/m^2, with 90% survival for a similar growing period in raceways. The resulting harvested biomass was 1.9 kg/m^2 and no stunting occurred. The postlarvae were then thinned to 220-300/m^2 and grown for another 49 days, resulting in 81% survival, average growth of 1.07 g/week, and a final average weight of 7.3 g. For the 3,200 postlarvae/m^2 stock, they fed *Artemia* nauplii for 8 days beginning at 160 nauplii per postlarvae per day during the first 2 days after stocking, and reduced the quantity by half every other day to 20 *Artemia* nauplii per postlarvae per day on the eighth day.

Starting the first day of holding, dry feed was given 6 times a day, with a ration size of crumble 0 (particle size range <0.59 mm) for postlarvae with an average weight of 1-15 mg. They also recommended feeding a supplemental feed starting on the second day consisting of frozen adult *Artemia;* and a number of other supplemental feeds per week could be used depending on postlarvae fouling level and health condition. If heavy fouling or surface bacterial contamination is detected, frequent *Artemia* feeding should be considered to enhance molting. Under low incidence of integument fouling and with good animal health, supplemental feeding should be given only twice a week. The total amount of *Artemia* given during one cycle should not exceed 10% of the total expected shrimp biomass at harvest.

A similar feeding regime with *P. monodon* postlarvae is described in Treece and Fox (1993) where 6 *Artemia* nauplii per ml were fed to Pl4. An additional dry ration was fed at a rate of 100% body weight, splitting the ration into 4 aliquots per day. Postlarvae were held under these conditions to day 18 with approximately 59% survival. The *Artemia* was tapered off completely by day 11 and 200% body weight dry feed was fed from postlarval-6 stage on. A water exchange rate of 100% per day was found to be adequate in an oceanic environment. Water was filtered through sand and disinfected with photozone (UV and ozone).

Water Quality in Acclimation and Holding Facilities

Water quality should be carefully monitored whenever postlarvae are held in tanks.

Maximum acceptable levels (which also reduce growth 1-2%) of ammonia (NH_3-N) is 0.1 mg/L (which corresponds to 1.8 mg/L of the unionized ammonia level NH_4-N at 28 °C, pH 8.0, salinity of 27 ppt). Since most algae utilize ammonia, placing algae in the acclimation or holding tanks will not exacerbate problems with ammonia. Adding pure oxygen to keep oxygen at saturation will also help reduce problems with ammonia.

Nitrite should be measured occasionally to be sure the level is below 1 mg/L; the level can be determined by electrode, commercial test kit, or analytical method.

Any detectable concentration of hydrogen sulfide is undesirable, since a concentration of 0.01 mg/L to 0.05 mg/L of H_2S may be lethal; even at low concentrations it is easily recognized by rotten egg smell. Most acclimation and holding facilities procedures involve the addition of EDTA at 2 ppm or higher. EDTA is a chelator which helps control debris adhering to appendages of shrimp and increases the availability of trace metals in sea water.

Releasing Postlarvae into Ponds

Ponds should be carefully prepared for stocking. This entails draining, completely drying, liming the bottom and then refilling. These procedures are detailed in Chapter 5. When refilling begins, the initial fertilization regime is also begun. Two methods for this are described in Chapter 5.

Ponds should be carefully inspected before stocking to ensure that a suitable algal bloom is present and that there are no predators.

Releasing shrimp in the cool of the morning is better for animals because workers are rested and less likely to make a late-night mistake by hurrying.

Harvesting the acclimated animals is a critical step since they have been subjected to stress and care must be taken to avoid additional stress during this handling.

The transport tanks should be cleaned and dried as described above. The tank is then filled with water from the reservoir tanks or the pond where the postlarvae will be stocked. At this point, water quality parameters should be equivalent for the two water sources.

A final microscopic evaluation of the postlarvae should be conducted before draining of the acclimation tanks proceeds.

As the postlarvae are drained from the bottom of the tank into a recipient container, an airline should be placed in the container. This helps keep the mesh on the harvest container drain free of particulate matter and prevents overflow. As the tank drains, wash down the sides to prevent postlarvae from adhering to the sides.

Take care to only drain about 20% of the volume of the acclimation tank into the recipient container before transferring the postlarvae into the transport tank. Repeat the procedure until the tank is drained. This should take no more than 30 minutes. Each transport tank should have a final density of no more than 800 postlarvae per liter. The transport tanks should be continuously oxigenated.

The postlarvae should be drained from the transport tank into the pond at intervals of 50 meters. This should be done through a hose partially submerged in the pond. Care should be taken to avoid disturbances near the point of discharge to prevent the postlarvae from burying themselves in the pond bottom. The postlarvae should be unobtrusively monitored as they enter the pond. Larvae are always released on the upwind side of the pond so the wind and waves will help disburse them after stocking.

To monitor post-stocking survival, mesh cages can be used. Two cages are used per pond and positioned near the edge of the pond in a minimum of 50 cm water depth. One hundred postlarvae are stocked in each cage. Forty-eight hours after stocking, the postlarvae are removed and the percent surviving calculated. The average of the two survival rates is taken as the stocking survival rate for the pond. This should be greater than 85%. The pond sides should also be monitored for dead postlarvae.

APPENDIX 1
ACCLIMATION CONTROL SHEET

Source: Villalon 1994.

Pond Number____________________ Date ____________________________

Supplier_____________________________

DELIVERY:

Time PL's harvested ____________ Count conducted by farm representative?

Water temperature in bags _____°C

Salinity in bags _______ ppt Yes ________ No _________

Number of PL's __________________

Results of stress test ______________

PARAMETERS AT ARRIVAL: (Individual bags)

Time of arrival _______________ (_________________________________)

Dissolved O_2 __________ average ppm (_________________________________)

Average pH ___________ (_________________________________)

Average water temperature ______ °C (_________________________________)

Average salinity _____ ppt

PARAMETERS AT ARRIVAL:

Time in tanks (hr)_____________

Dissolved O_2 in tanks (average) ____ ppm

pH in tanks (average) __________

Temperature in tanks (average)______°C

Salinity in tanks (average) ______ ppt

INITAL VOLUMETRIC COUNT (optional)

TOTAL PL´s__________________

Live PL's _______________________

Dead PL's ______________________

% mortality in transport____________ %

FINAL VOLUMETRIC COUNT (optional)

TOTAL PL´s _____________________

Live PL's _______________________

Dead PL's ______________________

% mortality during acclimation_______ %

MICROSCOPIC EVALUATION OF POSTLARVAE

(Observe 20 postlarvae each time)

Qualities	*IN ACLIMATION*		
	Initial	Half way point	Final
Gut fullness index Fouling of setae Opacity of tail Deformities			
Average			

ACCLIMATION

	AVERAGE PARAMETERS				EVALUATION AVERAGE							
Time	Sal	Temp	pH	O_2	Activity	Swimming erratically	Opacity	Molt	% Gut fullness	Mortality	Cannibalism	Observations
Tank												

Container

No. 1 No. 2 Average

%Survival after 48 hours: (_____ % ______%) _________%

Biologist: ________________________________

7

BIOSECURITY IN SHRIMP FARMING

BIOSECURITY IN SHRIMP FARMING

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Introduction

The most important diseases of cultured penaeid shrimp, in terms of economic impact, in Asia, the Indo-Pacific, and the Americas have infectious etiologies. Among the infectious diseases of cultured shrimp, certain virus-caused diseases stand out as the most significant. The pandemics due to the penaeid viruses WSSV (White spot) and TSV (Taura Syndrome), and to a lesser extent to IHHNV (Infectious Hypodermal and Hematopoietic Necrosis virus) and YHV (Yellow Head), have cost the penaeid shrimp industry billions of dollars in lost crops, jobs, and export revenue (Table 1). The social and economic impacts of the pandemics caused by these pathogens in countries in which shrimp farming constitutes a significant industry have been profound. In the wake of the viral pandemics the shrimp culture industry has sought ways to restore the industry's levels of production to the "pre-virus" years. The application of biosecurity to shrimp farming is central to those efforts.

Table 1. Estimated economic losses due to shrimp diseases.

ECONOMIC LOSSES

VIRUS	Year Discovered	Estimated Losses To date
WSSV - Asia	1992	$ 4-6 BILLION
WSSV - Americas	1999	$ >1 BILLION
TSV	1991-92	$ 1-2 BILLION
YHV	1992	$ 0.1-0.5 BILLION
IHHNV*	1981	$ 0.5-1.0 BILLION

* Includes Gulf of California

"Biosecurity" has become a commonly used term in the shrimp culture industries of the world only in the past few years. However, the concept that it represents is, and has been, the foundation of nearly all mature and successful food animal producing industries for decades. Many producers of cattle, swine, poultry, and many species from aquaculture, like trout, salmon, and catfish, rely on the principles of biosecurity. But what is "biosecurity"? Neither recent editions of Dorland's Medical Dictionary nor the Webster's New Collegiate Dictionary define the term. The term may have been born in one of the food animal producing industries where profits and sometimes even the survival of businesses, are dependent on the strict adherence to the concepts of biosecurity.

In the poultry industry, biosecurity has been defined as an essential group of tools for the prevention, control, and eradication of economically important infectious diseases (Zavala 1999).

In the wake of the epizootics due principally to the shrimp viruses TSV and WSSV that swept through the main penaeid shrimp growing regions of both Asia and the Americas, the shrimp farming industry now seems intent to utilize any of the applicable concepts of biosecurity in its farms.

The poultry industry's definition of biosecurity may be simply summarized as the exclusion of pathogens from cultured stocks at farms. The application of biosecurity concepts to many of the existing types of shrimp farming, as they have been applied to poultry for example, is not something that can be accomplished easily or in the short term. The industry has thousands of hectares of farms and hundreds of hatcheries, few of which were designed to afford managers with much of an opportunity to totally prevent a particular pathogen from being introduced and becoming established. Nonetheless, biosecurity is a broad concept and much can be done to reduce losses due to particular pathogens by modifying existing farms and their management routines in order to apply biosecure concepts. Furthermore, the application of biosecurity concepts to shrimp aquaculture, will contribute significantly to making the industry much more sustainable and environmentally responsible well into the future. Key to any effort at excluding pathogens are the following principles and tools:

- Availability of adequate diagnostic and detection methods for the pathogens of concern.
- Control of cultured shrimp stocks.
- Adequate environmental control to prevent the introduction of pathogens of con cern.
- Development and continuous implementation of policies and management practices that exclude pathogens.
- Disinfection and pathogen eradication methods to contain and eradicate disease outbreaks due to pathogens of concern.

First on the above list is the requirement that adequate disease diagnosis and pathogen detection methods are available to the industry. Highly sophisticated methods for pathogen detection in various sorts of samples are of little value to the shrimp farming industry if those methods are not sufficiently sensitive or accurate, or if adequate methods do exist but they are not readily available to an industry that could benefit from their application and use.

The global penaeid shrimp farming industry is nearly 30 years old and it now produces about 800,000 metric tons of shrimp annually from its farms. The importance of the industry to the global economy is reflected in those production numbers and by the millions of persons employed directly or indirectly by the industry. That farmed shrimp are among the most important foreign exchange earners for many tropical and subtropical coastal nations further documents the importance of the industry. Yet ironically, most of the penaeid shrimp farming industry depends on the capture of wild postlarvae or broodstock to provide the "seed stock" used to stock farms (Argue and Warren 1999). While some application of biosecurity principles are possible with an industry that uses wild stocks for seed production, consistency in preventing disease and pathogen introduction is problematic. As long as the industry remains dependent on wild stocks, it cannot expect to be consistently successful in excluding pathogens of concern. The use of wild broodstock, and especially wild postlarvae, leaves the farms that rely on this source of seed stock particularly venerable to the introduction of pathogens of concern.

While numerous methods have been incorporated into the operational design and management of shrimp farms previously affected by TSV and WSSV to eradicate them and to insure that they are not reintroduced, none can be expected to provide much protection against crop losses in farms that use seed stock derived from wild stock sources. The use of only domesticated shrimp stocks that have a known history of being free of pathogens of concern can help to mitigate this risk. However, a specific pathogen-free history comes only from a long-term captive breeding and disease surveillance program at a facility that has a fully functional and effective biosecurity plan.

This section of the manual reviews the concepts and principles of biosecurity, with a particular emphasis on the available diagnostic methodologies for pathogen detection, disease diagnosis, and for the development and use of domesticated lines of specific pathogen-free shrimp stocks. Shrimp taxonomy used in this section is according to Holthuis (1950).

PRINCIPLES OF PATHOGEN EXCLUSION

Epizootiology and Pathogen Control

Disease in shrimp farming may be defined as a biotic or abiotic condition or factor that adversely affects culture performance (Lightner 1996). Biotic diseases of shrimp are those that have living agents as the cause, while abiotic diseases may be caused by environmental or physical extremes (temperature, hypoxic conditions, nitrogen super-saturation, extremes of pH, etc.), chemical toxicants, pesticides, etc., nutritional deficiencies or imbalances, improper handing, etc. Within biotic diseases are diseases of infectious and non-infectious etiologies. The list of biotic diseases affecting shrimp is not too different from the list of diseases that affect other animals. Many of the major groups or major causes of disease in vertebrates are represented among the causes of disease in penaeid shrimp. Shrimp have infectious diseases caused by viruses, rickettsia, true bacteria, protozoan and helminth parasites, etc. They have benign and neoplastic tumors, and they develop nutritional diseases when fed inadequate diets (Lightner 1988, 1993a, 1993b, 1996).

When the epizootiology of shrimp diseases is considered in terms of their historic and current distribution, some trends become quickly apparent. Tables 1-2 list the principal diseases of culture penaeid shrimp in the Western and Eastern Hemisphere. Some of the most important diseases (and their etiological agents) were once limited in distribution to either the Western or Eastern Hemisphere. However, the international movement of live (for aquaculture) and dead (commodity shrimp for commerce) has led to the transfer and establishment of certain pathogens from one hemisphere to the other.

WSSV was moved from Asia to the Americas by this route and TSV was moved in the opposite direction. Perhaps these transfers and introductions could have been prevented if the industries and governments of the exporting and importing countries had known of the risks posed by their actions and if the appropriate disease diagnostic and pathogen detection methods had been readily available when the most damaging transfers were being made. Unfortunately, since its beginnings, growth and development of the penaeid aquaculture industry has had as one of its characteristics a "gold rush" mentality. The industry has too often moved forward on development of new farming regions, transfer of live or dead shrimp stocks, etc., well before the risks or environmental consequences were considered, let alone assessed. Many of the most significant shrimp pathogens were moved from the regions where they initially appeared to new regions even before the "new" pathogen had been recognized, named, proven to cause the disease, and before reliable diagnostic methods were developed. The diseases due to the shrimp viruses IHHNV, TSV and WSSV all were transferred with live shrimp stocks from country to country and from one continent to another before their etiology was understood.

While biosecurity has as its goal the exclusion of known pathogens for which epizootiological data is available and for which there are adequate diagnostic and detection methods, the application of biosecure practices can also reduce the likelihood of the introduction of an unknown or poorly understood pathogen. Nonetheless, before the principles of biosecurity can be applied to a particular shrimp farming region or to an individual facility, it is necessary to identify which pathogens are to be targeted for exclusion. **The listed pathogens in a biosecurity program must be excludable**. Figure 1 illustrates graphically the interaction between host, environment and pathogen. Therefore, the epizootiology of a pathogen (i.e. its hosts, biology, and methods of transmission) must be understood to permit managers to understand how the pathogen is transmitted and how to prevent its entry and spread. Adequate diagnostic methods for the disease and detection methods for its agent are also essential tools in biosecurity. Adequate diagnostic methods means reliable, sensitive and readily available.

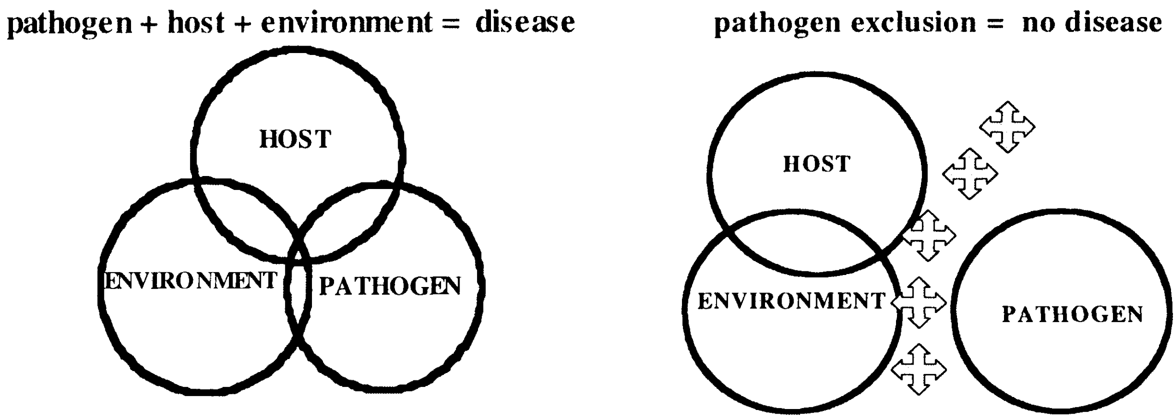

Figure 1. Pathogens are generally found in any organism's environment, often without ill effects. The presence of pathogens may result in disease due to a variety of factors related to the host and its environment. Only when a pathogen is excludable can disease be prevented.

It is impractical, if not impossible, to expect biosecurity to lead to the development of "disease free" or "pathogen-free" shrimp stocks. It is equally impractical to expect to farm such stocks in an environment where every potential pathogen is excluded.

Shrimp have as part of their natural microbial flora and in their aquatic environment, a large and diverse population of microorganisms, some of which are facultative pathogens ready to strike when the shrimp become compromised by any number of stressors. Certain *Vibrio* species provide a good example of organisms that live in the shrimp's environment, often as part of the normal microflora inhabiting the surface of their cuticle or colonizing areas of the gut or hepatopancreas. Some *Vibrio* species can become deadly pathogens in "stressed" shrimp.

"Stress" in shrimp is a poorly defined condition that is difficult to measure, and it has more causes than are even known. Its causes can range from exposure to environmental extremes to inadequate nutrition. Most penaeid shrimp have the best culture performance (i.e. growth and food conversion efficiency) at water temperatures near their upper tolerance limit for a particular life stage of the species. Farms and management practices must be tailored to operating near the temperature tolerance limit, and be prepared to take corrective measures when "stress" and disease result from water temperatures becoming too high for too long. Hence, the farm siting, culture system design, the quality of feed used, stocking density, the farm's routine management practices, and other factors can have a profound effect on the amount of "stress" to which farmed shrimp stocks are subjected. A key feature of biosecurity is that farm design, feeds and feeding, and the quality of management are essential components to successful shrimp farming (i.e. broodstock facility, hatchery, or growout farm).

The International Office of Epizootics (OIE) is the administrative arm of the World Animal Health Organization. OIE maintains at its web site (www.oie.int) and regularly publishes the International Aquatic Animal Health Code and Diagnostic Manual. The OIE currently has nine crustacean diseases (eight of which are penaeid virus diseases) on its list of pathogens which pose a threat to international commerce, fisheries, and crustacean aquaculture (especially shrimp). Tables 5-7 list the OIE notifiable and listed shrimp viruses and the available diagnostic and detection methods for each. Before a disease may be included on the OIE lists of notifiable and listed diseases, several criteria must be met:

- the etiological agent must be known;
- reliable diagnostic(s) methods must be available; and
- the disease must be a significant disease of local, regional, or international importance.

Pathogen lists, such as the OIE list, are useful models for setting up a biosecurity program that is based on exclusion of a list of specific pathogens and the diagnostic methods for surveillance and diagnosis.

Current Diagnostic Methods

Modern penaeid shrimp diagnostic and research laboratories are based on traditional methods of disease diagnosis and pathogen detection that have been adapted from methods used in fish, veterinary and human diagnostic laboratories. In penaeid shrimp pathology, diagnosticians rely heavily on case history, gross signs and behavior, morphological pathology (direct bright-field or phase contrast light microscopy and electron microscopy) and classical microbiology (bacteriology and mycology) (Table 3, Figure 2).

Paradoxically, important techniques involving tissue and cell culture and hematology and clinical chemistry, which are virtual cornerstones of vertebrate biomedical research, diagnostics, and pathology, have either not been successfully applied as routine diagnostic tools in penaeid shrimp pathology (in the case of cell and tissue culture), or have not provided routinely practical diagnostic data (in the case of hematology and clinical chemistry). In marked contrast, methods based on pathogen detection using antibody-based methods (employing polyclonal and monoclonal antibodies) and, especially, molecular methods (using gene probes and Polymerase Chain Reaction-PCR) have been found to provide accurate and standardizable methods for disease diagnosis and pathogen detection to the penaeid shrimp culture industries, especially for certain penaeid viruses (Lightner 1996, 1999a, 1999b; Tables 6 & 7).

Classical Methods

Methods for the detection of pathogens and the diagnosis of diseases that are currently in use by shrimp pathologists and by diagnostic labs have been reviewed many times in the past decade (Baticados 1988; Baticados et al. 1990; Liu 1989; Johnson 1990, 1995; Brock 1991, 1992; Brock and Lightner 1990a, 1990b; Brock and LeaMaster 1992; Brock and Main 1994;

Fulks and Main 1992; Lightner 1988, 1992, 1993a, 1993b, 1996; Lightner and Redman 1991, 1992, 1998; Lightner et al. 1992a, 1992b, 1994; Limsuwan 1993). Diagnosticians working with penaeid shrimp continue to rely heavily on the "classical" diagnostic methods (Table 3). Among the most important of these are gross and clinical signs, with the most commonly applied laboratory tests being direct examination and microscopy using the light microscope, classical microbiology with isolation and culture of the agent, and routine histology and histochemistry (Bell and Lightner 1988; Lightner 1996). Virtually every functional shrimp pathology/diagnostic laboratory today is equipped to do direct light microscopic methods and routine procedures in histology and bacteriology.

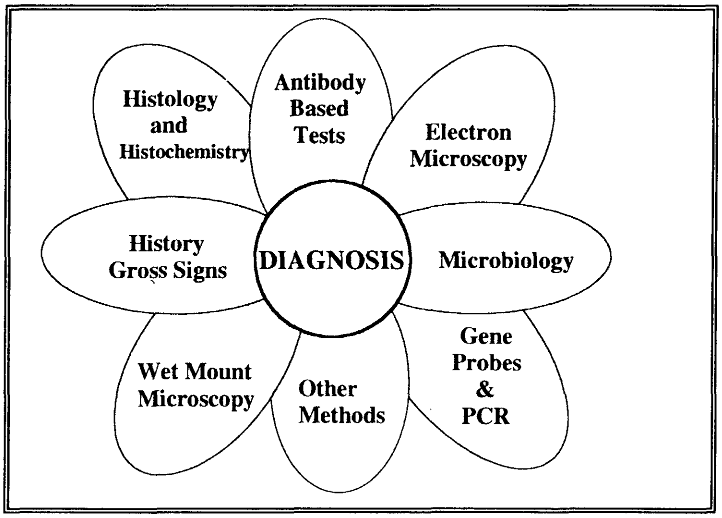

Figure 2. A wide range of diagnostic techniques exists for shrimp disease. The method of choice will vary with each disease and more than one may be necessary to definitively identify a pathogen.

Other "classic" diagnostic techniques that are important, but are used less frequently, include techniques such as bioassay and enhancement, which are used for the detection of subclinical or carrier-state infections by certain pathogens (Lightner et al. 1983b; Overstreet et al. 1988; Brock and Lightner 1990a; Lightner 1996; Lu et al. 1995a). Methods used by shrimp pathologists more as research tools, but occasionally for diagnostic purposes, are transmission and scanning electron microscopy (Momoyama et al. 1995; Johnson and Cassout 1995), and antibody-based tests with immune sera prepared in mammals (Lightner 1996).

Hematology and Clinical Chemistry

It is interesting, and perhaps somewhat of a paradox, that hematology and clinical chemistry, two of the principal diagnostic tools of human and veterinary medicine, are so seldom used as a diagnostic tool in penaeid shrimp pathology. However, while there have been a few studies in which changes in hemolymph parameters, such as hemocyte count, clotting time, glucose, non-protein nitrogen, ammonia, SGOT (Serum Glutamic Oxaloacetate Transaminase), alkaline phosphatase, total serum protein, etc., were shown to result from infectious disease in shrimp and lobsters (Stewart et al. 1969; Stewart and Rabin 1970; Hose et al. 1984; Stewart 1993), almost none of these test have been adapted to routine diagnostic use. Only hemolymph clotting time and changes in total hemocyte count seem to be used by shrimp disease diagnosticians (Lightner 1996).

Tissue Culture

Another paradox of shrimp pathology is the virtual absence of cell and tissue culture methods as diagnostic tools. Cell and tissue culture form one of the diagnostic cornerstones of plant, veterinary, and human pathology and biomedical research. Tissue culture methods are central to the diagnosis of most of the viruses of finfish (Thoesen 1994). Even for insects (which, like crustaceans are arthropods) there are numerous cell lines, some of which have been available for decades (Vago 1971; Maramorosch and Mitsuhashi 1982). A number of research groups have developed and improved upon the methods for primary cells from penaeid shrimp (Chen et al. 1986; Itami et al. 1989; Rosenthal and Diamant 1990; Ellender et al. 1992; Luedeman and Lightner 1992). Some researchers have used primary cultures of shrimp cells to attempt to grow in vitro certain shrimp viruses like MBV, YHV, and WSSV (Chen and Kou 1989; Lu et al. 1995b; Tapay et al. 1996a; Crane and Benzie 1999). While advances in penaeid shrimp primary cell culture are encouraging, shrimp tissue culture remains in the research and development phase as a diagnostic tool (Crane and Benzie 1999).

Toxicology and Analysis

Non-infectious diseases of penaeid shrimp are common in cultured shrimp (Lightner 1993b). Many are due to environmental extremes of temperature, salinity, pH, and other factors. Others are due to nutritional imbalances and deficiencies, and still others are due to toxicants (Lightner 1993a, 1993b). Toxicity syndromes may be due to the shrimp's own metabolites like ammonia and nitrite, or to toxic metabolites from such sources as moldy feed ingredients or feeds. Industrial and agricultural toxicants (certain heavy metals, some pesticides, and toxic chemicals) also occasionally cause disease and losses in cultured shrimp (Baticados et al. 1990; Brock 1992; Flegel et al. 1992; Lightner 1993b).

Shrimp affected by some non-infectious disease syndromes present unique gross signs and lesions that can provide a definitive diagnosis. However, most require confirmation of the causative agent by laboratory analysis (Brock 1992; Lightner 1993b; Brock and Main 1994). Examples of some toxic diseases that can be diagnosed solely from histological demonstration of pathognomonic lesions include hemocytic enteritis caused by blue-green algae toxicity, and presumably by other potent endotoxin producing organisms, in which prominent inflammatory lesions of the midgut are present (Lightner 1996), and a toxicity syndrome due to the agricultural fungicide benomyl in which unique lesions occur in the hepatopancreas (Lightner et al. 1996). While aflatoxicosis and certain forms of black gill and shell disease also display unique histological lesions, these diseases provide examples of toxicity syndromes in which demonstration of the suspected toxicant in the appropriate sample(s) (i.e., water, sediment, feed, shrimp, etc.) with the appropriate analytical method is necessary to provide a definitive diagnosis. Likewise, nutritional diseases, such as cramped muscle syndrome, soft shell, carotenoid deficiency, and the ascorbic acid deficiency syndrome, present unique gross signs and histopathology (Baticados et al. 1990; Lightner 1988, 1993a, 1993b), but for most nutritional disorders, confirmation of the provisional diagnosis depends upon other information obtained from case history and analytical results.

Antibody-based Methods

Several antibody-based methods have been developed for use in shrimp disease diagnosis (Tables 6-8). Monoclonal antibodies (MAbs) have been developed for detection of several species of *Vibrio*, the causative agents of vibriosis in shrimp. Song et al. (1992) developed an enzyme-linked immunoassay (ELISA) test based on MAbs to *Vibrio vulnificus* and *V. harveyi*.

Chen et al. (1992) also developed a number of MAbs to a number of *Vibrio* spp., including species (*V. alginolyticus, V. parahaemolyticus, V. vulnificus*, and *V. harveyi*) that are commonly reported as causative agents of vibriosis in shrimp. However, none of these MAbs have been made available to the public.

Polyclonal (PAb) and monoclonal antibodies have also been developed as diagnostic reagents for shrimp viruses (Tables 6 and 7). Sano et al. (1984) developed a fluorescent PAb test for BMN, the agent of baculoviral midgut gland necrosis in *P. japonicus*, Lewis (1986) reported the application of an ELISA-based PAb test for BP (*Baculovirus penaei*) of American penaeids. More recently, PAbs have been developed and applied to the detection of other shrimp viruses. Tapay et al. (1996b) reported on the application of PAbs for the detection of rhabdovirus of penaeid shrimp (RPS; Nalda et al. 1992; Tapay et al. 1996b), and for YHV and WSSV (Lu et al. 1996; Nalda and Loh 2000) (Table 4).

Monoclonal antibodies (MAbs) have been successfully developed and a few of these have become available to the shrimp culture industry through commercial sources. Poulos et al. (1994a) developed MAbs to IHHNV, but reported problems with specifity. Specificity problems may have been related to the IgM nature of the MAbs developed to IHHNV. While the IgM MAbs developed reacted specificially with purified IHHNV or its capsid proteins in Western blots, they reacted nonspecifically with components in normal shrimp tissue, resulting in false positive reactions with uninfected shrimp tissue samples in ELISA-based assays (Lightner et al. 1992c; Poulos et al. 1994a). More recently, IgG class MAbs to TSV and WSSV have been developed (Poulos et al. 1999; Poulos et al. submitted) which do not have the specificity problem. MAbs to TSV and WSSV are commercially available from DiagXotics, Inc. (Wilton, CT, USA).

Although the development of antibody-based tests for the more important shrimp pathogens has lagged behind the development of molecular detection and diagnostic methods, it is very likely that the use of tests based on polyclonal and monoclonal antibodies will become much more common in shrimp diagnostic laboratories in the next few years. Because of their speed, versatility, relatively low cost, simplicity, and reasonably good sensitivity, monoclonal antibody based tests are potentially very useful as a routine diagnostic tests even in the most modestly equipped diagnostic laboratories (Mailhe et al. 1992; Reddington and Lightner 1994).

Molecular Methods for Diagnosis and Pathogen Detection

Molecular methods (gene probes and DNA amplification using the polymerase chain reaction - PCR) have recently been applied to the diagnosis of certain infectious diseases of penaeid shrimp. Development and application of the first gene probe to the diagnosis of the shrimp virus IHHNV (Table 4) was reported only 8 years ago (Lightner et al. 1992c; Mari et al. 1993a). The first generation of IHHNV gene probes was developed by extracting ssDNA from IHHNV purified from infected *L. vannamei* and *L. stylirostris* and cloned into E. coli-DH5 cells (Mari et al. 1993a). From the resultant libraries of cloned fragments of IHHNV DNA, five clones with DNA inserts of 2.0 Kbp or larger were selected for further development. From these clones, the first DNA probes to a shrimp virus were developed (Mari et al. 1993a).

When labeled with (what was once traditional) radioactive tags, the use of gene probes was an option for only the best equipped diagnostic and research laboratories. However, the application of non-radioactive labeling methods has made gene probe technology readily available to shrimp research and diagnostic laboratories. The first non-radioactive gene probes for shrimp pathology were developed employing the non-radioactive *Genius* TMI Kit (Boehringer Mannheim, Inc.), which contains digoxigenin-11-dUTP (DIG) as the DNA label and uses an ELISA-based system for final detection (Lightner et al. 1992c; Mari et al. 1993a). This led to the development of the non-radioactive DIG-labeled gene probes for IHHNV and to their commercial application in diagnostic kits marketed under the product name "ShrimProbes™" by DiagXotics (Wilton, CT, U.S.A.).

Since the first gene probe to the shrimp parvovirus IHHNV was developed in 1992 (Lightner et al. 1992c; Mari et al. 1993a), the technology has been applied to the development of additional gene probes to other shrimp viruses, a rickettsia-like bacterium and a microsporidian (Table 8). At the present time, DIG-labelled gene probes have been developed and are available for the parvoviruses IHHNV and HPV, the picornavirus TSV, for the shrimp baculoviruses BP, MBV, for WSSV, and YHV, a rod-shaped ssRNA virus (Tables 5-8) (Lightner et al. 1992c, 1994; 2000; Bruce et al. 1993; Mari et al. 1993b, 1995; Poulos et al. 1994b; Nunan and Lightner 1997; Lightner 1996; Wang et al. 1995; Flegel et al. 1996). Using essentially the same technology, additional DIG-labeled gene probes have been developed for the causative agent of necrotizing hepatopancreatitis, an intracellular, rickettsial-like bacterium (Krol et al. 1991; Frelier et al. 1992, 1993, 1994; Lightner et al. 1992d; Lightner 1996; Loy and Frelier 1996), and for the microsporidian *Agmasoma* sp., which parasitizes *P. monodon* and *P. merguiensis* in southeast Asia (Pasharawipas and Flegel 1994; Pasharawipas et al. 1994). Many of these probes are commercially available as DIG-labeled probes or in kit form in the ShrimProbe™ line (Table 8) from DiagXotics, Inc. (Wilton, CT, U.S.A.).

DIG-labeled gene probes may be applied to shrimp diagnostics and pathogen detection in several ways. The protocol for the Genius™ System (Boehringer Mannheim Inc., Genius™ *System User's Guide for Membrane Hybridization*) was adapted for "dot blot" hybridization assays using homogenized tissue samples "blotted" and fixed onto membranes prepared from nitrocellulose or positively charged nylon. The method has been applied successfully to the detection of the penaeid shrimp viruses IHHNV and WSSV (Lightner 1996), the NHP bacterium (Loy and Frelier 1996; Lightner 1996), and in the detection of the microsporidian *Agmasoma* sp. (Pasharawipas and Flegel 1994).

In situ hybridization using protocols adapted from the Genius™ System developed by Boehringer Mannheim (Nonradioactive *In Situ* Hybridization Application Manual) may be used to detect viral and other genomic sequences with specific complementary DNA probes. The use of non-radioactive, DIG-labeled gene probes has been shown to provide a highly specific diagnostic method, since any non-specific tissue effects (which may result in a false positive diagnosis in a dot blot assay with homogenized tissue samples) can be readily distinguished from specific histological lesions that have reacted with the labeled probe (Lightner 1996). *In situ* hybridization methods have been developed for the shrimp viruses IHHNV, HPV, MBV, BP, the WSSV group, YHV, and TSV (Tables 6 and 7), for rickettsial-like bacterium NHP, and for the microsporidian *Agmasoma* sp. (Flegel et al. 1996; Lightner 1996).

The polymerase chain reaction (PCR) has had numerous recent applications to pathogen detection and shrimp pathology research (Tables 6 and 7). In PCR, small, otherwise undetectable, amounts of DNA can be amplified to produce detectable quantities of the target DNA. This is accomplished by using specific oligonucleotide primers designed for the target DNA sequence. The resultant PCR product may then be compared to a known standard using gel electrophoresis, by reaction with a specific DNA probe of PCR products blotted directly onto a membrane or to the PCR products in Southern transfers. In some applications PCR products themselves may be labeled with DIG and used as specific DNA probes (Innis et al. 1990; Perkin Elmer 1992).

When DNA sequence information is known for specific nucleic acid sequences (of penaeid shrimp viruses, bacteria, etc.) primers can be synthesized to target specific nucleotide sequences. The unique target sequences may belong to a virus, a bacterium, or to any nucleic acid sequence. Various computer programs exist which aid in selection of optimal primers, provided target DNA sequence information is available (Innis et al. 1990; Perkin Elmer 1992).

PCR has been applied to research and pathogen detection for most of the shrimp viruses of concern to modern day shrimp culture (Tables 6 and 7) (Wang et al. 1996; Nunan et al. 2000; Lightner 1999b). Other applications of PCR to shrimp pathology research and pathogen detection include reports of the application of PCR to the detection of bacterial pathogens such as the NHP bacterium (Loy et al. 1996) and *Vibrio penaeicida* (Genmoto et al. 1996).

There is a growing need to standardize and validate the DNA-based diagnostic methods and the laboratories that use them (Walker and Subasinghe 1999). Standardization of DNA-based diagnostic methods is almost inherent in the nature of the tests. That is, a specific DNA probe, or a specific set of primers, that is used to demonstrate the presence or absence of a unique DNA or RNA sequence does not vary from batch to batch. Hence, with proper controls, these DNA-based methods are readily standardized (Reddington and Lightner 1994).

However, despite the growing dependence of the shrimp culture industry on DNA-based diagnostic methods, none of the tests that are available from commercial sources nor from the literature have been validated using controlled field tests. Likewise, there are no formal accreditation or certification programs yet in place to assure that test results from technicians and laboratories running the tests are indeed accurate and properly controlled (Lightner and Redman 1998; Lotz and Lightner 1999; Lightner 1999b).

The implementation of a formal program by appropriate international agencies or professional societies is needed to validate new diagnostic methods and to periodically review the accreditation and certification of diagnosticians and diagnostic laboratories. The establishment of regional reference laboratories for DNA-based diagnostic methods of penaeid shrimp/prawn pathogens would fit well into such a program with the goal of making these methods uniform, reliable, and readily applicable to disease control and management strategies for viral diseases of cultured penaeids.

DISEASE MANAGEMENT METHODS

A variety of strategies have been attempted for the control of viral diseases in penaeid shrimp aquaculture. These strategies range from the use of improved culture practices (i.e. where sources of virus contamination are reduced or eliminated, sanitation practices are improved, stocking densities are reduced, etc.) to stocking "specific pathogen-free" (SPF) or "specific pathogen resistant" (SPR) species or stocks. Most recently, there have been some studies made on the use of vaccines and immunostimulants for the prevention of viral diseases in shrimp.

Strategies for Control of Virus Disease:

In the Americas many strategies have been employed in efforts to reduce production losses due to the enzootic viruses IHHNV, BP and TSV.

Prevention of Baculovirus in Hatcheries:

Improved husbandry practices have been successfully employed for the control of BP, and for nearly a decade, this virus has seldom been reported as a serious constraint to successful shrimp culture. This was accomplished because BP's infection cycle can be interrupted with routine hatchery management practices. BP is a gut-infecting baculovirus which is transmitted from shrimp to shrimp exclusively *per os* [1] (Johnson and Lightner, 1988; Overstreet et al., 1988; Overstreet, 1994). Hence, with BP, as well as with MBV and BMN (all gut-infecting baculoviruses of penaeid shrimp), infection from parent to off-spring in the hatchery has been prevented by eliminating fecal contamination of spawned eggs by virus-contaminated feces from spawning adults and by the use of adequate sanitation practices (Momoyama, 1988, 1989a, 1989b, 1989c, 1989d).

A number of innovative methods have been developed for reducing or eliminating fecal (containing baculovirus) contamination of spawned eggs. The simplest of these has been

[1] Per os = by mouth

the use of hatching vessels in which embryonating shrimp eggs are rinsed with clean seawater, and in which hatched nauplii are passively rinsed by continuously flowing clean seawater and separated from contaminants and "diseased" siblings by collection using the normal phototaxic response of "healthy nauplii". Chemical rinses of spawned eggs and collected nauplii with disinfectants like chlorine, ozone, iodophores, and formalin are also commonly used in shrimp hatcheries in the Americas to help prevent BP, as well as vibriosis and other diseases. The use of routine sanitation and disinfection procedures for hatchery equipment and tanks after each use are also commonly used to prevent the occurrence of viral infections due to BP, or to limit their tank to tank spread when they do occur.

Some hatcheries individually spawned their gravid females, collected any fecal strands, and scanned these using simple bright field microscopy for BP occlusion bodies. In like manner, some hatcheries sacrificed broodstock females after spawning, excised the HP, and examined it for the presence of BP occlusion bodies using direct microscopy of tissue squash preparations. To prevent BP infections and disease from occurring in the larval rearing tank systems, the spawns from females, found to be BP-positive from examination of their feces or excised HP, were discarded.

Avoidance through Pathogen Exclusion and Development of SPF Shrimp:

Disease management through exclusion of specific pathogens is commonplace in modern agriculture. This concept of developing stocks that are specific pathogen free (SPF) and rearing of these stocks in regions where the specific pathogens of concern are excluded has been used in the Western Hemisphere with mixed success. The successful application of the SPF concept is, of course, dependent upon the absence of the pathogen(s) of concern in the stocks being reared (or that are present), on the availability of sensitive and accurate detection and diagnostic methods for the pathogen(s), and the presence of an effective barrier (i.e. geographic, government mandated import restrictions, etc.) to prevent the introduction of the specific pathogen(s) intended to be excluded.

In the Western Hemisphere, SPF stocks of *L. stylirostris* and *L. vannamei* have been developed and these are being cultured successfully in some locations (Wyban, 1992; Wyban et al., 1992; Carr et al., 1994; Pruder et al., 1995; Lightner, 1996b). The International Council for Exploration of the Seas (ICES) Guidelines (Sindermann, 1990), were followed for the development of these stocks. The determination of which specific pathogens the selected stocks were to be free of was based on a working list of specific, excludable pathogens (Wyban, 1992; Lotz et al., 1995). The most current working list for the U.S. Marine Shrimp Farming Consortium includes eight viruses (WSSV, YHV, TSV, IHHNV, HPV, BP, MBV, and BMN), certain classes of parasitic protozoa (microsporidians, haplospordians, and gregarines), and helminth parasites (cestodes, trematodes, and nematodes). In the spirit of the ICES Guidelines, each "SPF candidate population" of wild or cultured shrimp stocks of interest were identified (Table 3).

A Working List of Specific Pathogens
for "SPF" Penaeids in United States[1]

Pathogen	Pathogen Type	Category
VIRUSES		
TSV	picornavirus	C-1*
WSSV (SEMBV, etc.)	'nimavirus'	C-1*
YHV, GAV, LOV	corona-like viruses	C-1*
IHHNV	parvovirus	C-2**
BP	occluded baculovirus	C-2**
MBV	occluded baculovirus	C-2**
BMN	nonoccluded baculovirus	C-2**
HPV, SMV	parvoviruses	C-2**
PROTOZOA		
Microsporidians	Microsporidia	C-2
Haplosporidians	Haplosporidia	C-2
Gregarines	Apicomplexa	C-3
METAZOAN PARASITES	helminth worms	C-3

[1]For 1995-2001 seasons; * = OIE notifable; ** = OIE listed

Table 3. SPF stocks are to be free of the listed pathogens.

The process of developing an SPF strain begins with taking samples of the available stock and these are tested using appropriate diagnostic and pathogen detection methods for the specific pathogens of concern. If none were found, a founder population (F_0) of the "candidate SPF" stock was acquired and reared in primary quarantine. During primary quarantine, the F_0 stock was monitored for signs of disease, sampled, and tested periodically for specific pathogens. If any pathogens of concern were detected, the stock was destroyed. Those stocks that tested negative for pathogens of concern through primary quarantine (which ran from 30 days to as much as 1 year for some stocks) were moved to a separate secondary quarantine facility for maturation, selection, mating, and production of a second (F_1) generation. The F_1 stocks were maintained in quarantine for further testing for speci-fic pathogens of concern. Those that tested negative were designated as SPF and used to produce domesticated lines of SPF and "high health" (Wyban et al., 1992; Pruder et al. 1995). SPF and high health stocks of *L. vannamei* were used successfully in U.S. shrimp farms in 1993 and 1994, and resulted in nearly double the production per crop that had been previously obtained at the same farms in previous years when the farms cultured non selected lines of *L. vannamei*, which in previous crops, had been persistently affected by "runt deformity syndrome" (RDS) due to chronic infection by IHHNV (Pruder et al., 1995 ; Lightner, 1996a, 1996b) (Figure 2).

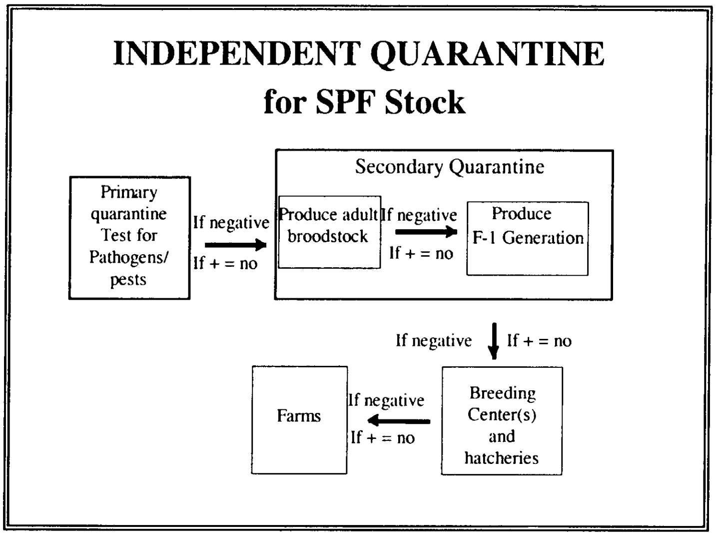

Figure 2.
Independent quarantine procedure for isolating and developing SPF stock.

Another interesting application of disease management through avoidance and the use of SPF stocks began in 1995 in Belize. The shrimp culture industry in this Central American nation is relatively small with less than 10 farms. Belize was seriously impacted by the TSV panzootic in 1994 (Lightner 1996b; Dixon and Dorado 1997). The shrimp farms in Belize are geographically isolated from other shrimp farming regions in adjacent countries (because most are situated on the Pacific coast), and with its location on the Caribbean side of the continent, it has no natural occurring wild stocks of the penaeid species (*L. vannamei* and *L. stylirostris*) that are likely to serve as reservoir hosts of TSV and IHHNV. Belize was uniquely suited to attempt to eradicate TSV and IHHNV. Seven of its farms were depopulated of all their shrimp stocks in late 1995; then each farm was thoroughly disinfected and dried out to eradicate potential sources of these viruses. The eradication program included pond disinfection (liming pond bottoms with calcium oxide at 5,000 kg/ha or chlorine at 10 ppm residual for 24-48 hr), pond dry-out and bottom tilling (to a depth of ~10 cm to ensure oxidation of contaminated pond-bottom detritus), farm implement and building disinfection (with chlorine or with formalin gas), spraying insecticides (to kill potential reservoir hosts like wild crabs and shrimps in supply drainage canals), and removal of frozen shrimp from storage from the country's packing plants (Dixon and Dorado, 1997). For the 1996 and 1997 seasons, these farms were stocked exclusively with SPF *L. vannamei*. From 1995 to late 2000, TSV has not been detected in Belize, and IHHNV has been found only at low prevalence rates. In the absence of TSV, the per crop average production of *L. vannamei* in 1996 at one farm was 891 kg/ha (heads on) with a stocking density of 15.5 PL/m^2, and survival to harvest has averaged 67%. In comparison, the same farm's production during the TSV panzootic of 1994 was 390 kg/m^2 (stocked at 18.3 PLS/m^2) with a survival of 36% (Dixon and Dorado, 1997). While the Belize experiment in TSV and IHHNV eradication may have been successful, duplication of its accomplishments elsewhere in the Americas may not be feasible. In these regions where total stock eradication is not feasible, other methods for virus disease management are being used.

Successful application of the ICES Guidelines and the SPF concept requires that specific pathogens are excludable. In situations where specific pathogens may not be excludable, the development and use of SPR stocks may be the only alternative. The fact that IHHNV and TSV have become widely distributed in the Americas indicates that either government or industry supported pathogen exclusion mechanisms and regulations must be implemented and enforced to achieve the goals of using SPF shrimp stocks, or, alternatively, that SPR stocks be developed and used.

Development and Use of Specific Pathogen Resistant (SPR) Stocks:

One alternative approach to developing SPF domesticated shrimp stocks, is to select and breed survivors of "specific pathogen-infected" (by pathogens like IHHNV, TSV, or WSSV) stocks to develop "specific pathogen-resistant" or SPR stock. Following this scheme, French researchers successfully developed a stock of IHHNV resistant *P. stylirostris* in French Polynesia (Weppe, 1992; Lightner, 1996b). This stock, designated as SPR-43, was developed by the French Research Institute for Exploration of the Seas (IFREMER) by breeding generations of IHHN survivors at the IFREMER stations in Tahiti and New Caledonia. After several generations, survival and culture performance of the stock improved. The stock was found to carry IHHNV at low rates of prevalence and severity of infection. When experimentally challenged with IHHNV, the SPR-43 stock was found to be resistant to IHHN disease (Weppe et al., 1992).

A second line of SPR *L. stylirostris* was developed in Venezuela. Its development followed the same strategy that was used by the IFREMER in Tahiti and New Caledonia. The founder stock was introduced to Venezuela from Panama. The founder may have been infected with IHHNV when it was introduced, or it became infected from imported stocks of *L. vannamei* after being imported into Venezuela. Generations of IHHN survivors were selected and reared until that stock began to perform as well as did the normally IHHNV resistant stocks of *L. vannamei* at the same farm. When the TSV panzootic swept through the Americas, the Venezuelan stock of *L. stylirostris* was found to be TSV resistant. This stock possesses resistance to IHHNV and TSV, and it was marketed as Super Shrimp™ in the Americas (Lightner and Redman 1998). Beginning in 1997 in some regions of Mexico, the SPR stocks of Super Shrimp™ (*L. stylirostris*) replaced *L. vannamei* stocks, which at that time made up >90% of the shrimp farmed in Mexico (Rosenberry 1996). However, the use of Super Shrimp declined in 1999-2000 after the WSSV epizootic reached Mexico and after an apparently new strain of TSV emerged that was pathogenic to Super Shrimp.

Selection for Disease Resistance:

Other shrimp farming interests are using wild or selected, domesticated SPF/SPR stocks of *L. vannamei* that show improved resistance to TSV and WSSV. Resistance to TSV was used as a selection criteria for selection and development of new lines of domesticated stocks of *L. vannamei*. Selected stocks in laboratory challenge studies with TSV and in pond trials at farms where the virus is enzootic have shown significant survival advantages over non selected stocks (Carr et al. 1997; Lotz and Lightner 1999). Natural selection for TSV resistance appears to be occurring in wild stocks as well. In regions like Ecuador and Honduras where TSV has been enzootic for several years, the practice of direct stocking of farms with wild PLs is providing steadily improving survival rates, even though shrimp displaying classic signs of TSV infection are commonplace. The same selective process for IHHNV resistance seems to be occurring in some wild stocks of *L. stylirostris* (Lightner, 1996b).

Initial efforts to select and breed TSV resistant, domesticated strains of *L. vannamei* have resulted in improvements in harvest survivals of 20 to 40% (Lightner, 1996b). Some selected lines of *L. vannamei* are highly resistant to TSV, giving >90% survival in laboratory challenge studies (White et al. 1999; Wyban 2000) and improved survival at farms in regions where the virus is enzootic (Wyban 2000). Some breeding programs using *L. vannamei* have reared survivors of WSSV epizootics and from them produced selected lines of F-1 progeny, some of which have shown improved survival rates compared to unselected stocks at farms affected by WSSV (Faria et al. 2000). The use of selective breeding for resistance to selected shrimp pathogens may provide the shrimp farming industry with improved, SPR stocks.

Other strategies to reduce disease losses:

Polyculture of shrimp with an omnivorous fish species also shows promise as a management method for reducing the impact of TSV in some shrimp growing countries. With this strategy, tilapia are grown in polyculture with shrimp like *L. vannamei*, and presumably, the tilapia consume dead and dying shrimp (from TSV) keeping other shrimp in the pond from becoming infected with the virus by cannibalism. With this method, improvements in shrimp production have been reported and a secondary crop of marketable fish is obtained (Green 1997).

The application of dietary immunostimulants as management tools for Taura Syndrome have also been reported (Brock et al., 1997; Dixon and Dorado, 1997; Klesius and Shoemaker, 1997; D. Dugger, personal communication, Immunodyne, Inc, Brownsville, TX). From slight improvements in survival (Klesius and Shoemaker, 1997; Dixon and Dorado, 1997) to survival rates of TSV-challenged *L. vannamei* comparable to unchallenged control groups have been reported (Dugger, personal communication).

Current Thoughts on TSV/WSSV Biosecurity

At the 4th Latin American Aquaculture Congress and Exhibition (October 25-28, 2000) held in Panama, a number of papers were presented in which the authors outlined the results of various strategies used in recent grow-outs for the control of losses due to WSSV. While there was some disagreements and variability of results, a few strategies seemed to provide improved survival and resulted in production of profitable crops. Some of these are outlined below:

- Dry and till ponds after the harvest. Better results are obtained if entire farm is depopulated, dried, limed, and tilled.
- Some farms use a pesticide (Sevin or Dylox) to kill all crabs resident in the ponds and seawater supply system. Other farms found this to be impractical or unneces sary.
- Treat all "new" seawater by coarse filtration and store in reservoir for 1 week or longer.
- Fill ponds with seawater passed through a 150-200 mesh filter bag being certain that no tears or leaks occur that would permit unfiltered water to enter pond.
- Reduce water exchange and use only water filtered through 150-200 mesh screen to fill ponds.
- Stock with PLs only from WSSV-free sources (confirmed by testing of broodstock and PLs by PCR) or domesticated SPF stock.
- Use lower stocking densities in ponds without aeration.
- Use mechanical aeration in ponds with higher stocking densities to reduce or eliminate need for water exchange.
- Use probiotic products to improve pond bottom condition and improve nutrient cycling.
- Add lime to maintain pH in an acceptable range and alkalinity >100 mg/L.

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Table 1
Major diseases of Indo-Pacific and east Asian penaeid shrimp.

VIRAL DISEASES	BACTERIAL & FUNGAL	OTHER DISEASES
White Spot Syndrome Virus	Vibriosis:	Epicommensals:
Yellow Head Virus group	- septic HP necrosis	- *Leucothrix mucor*
MBV group	- hatchery vibriosis	- peritrich protozoans
IHHNV	- luminescent vibrio	Gregarines
HPV group	Rickettsia	Microsporidians
REO group	Larval Mycosis	Nutritional imbalances
	Fusariosis	Toxic syndromes
		Environmental syndromes

Table 2
Major diseases of the American Penaeids

VIRAL DISEASES	BACTERIAL & FUNGAL	OTHER DISEASES
White Spot Syndrome Virus	Vibriosis:	Epicommensals:
Taura Syndrome Virus	- "Sindrome Gaviota"	- *Leucothrix mucor*
IHHNV	- hatchery vibriosis	- peritrich protozoans
BP group	- luminescent vibrio	Gregarines
HPV	- shell disease	Microsporidians
REO III?	NHP bacterium	Nutritional imbalances
LOVV?	Larval Mycosis	Toxic syndromes
RPS?	Fusariosis	Environmental syndromes
Yellow Head Virus?		Zoea II syndrome

Table 3.
Methods available to diagnosticians for shrimp disease diagnosis and pathogen detection.

METHOD	TESTS AND DATA OBTAINED
History	History of disease at facility or in region, facility design, source of seed stock (eg. wild or domestic specific pathogen-free, SPF, or resistant, SPR), type of feed used, environmental conditions, etc.
Gross, clinical signs	Lesions visible, behavior, abnormal growth, feeding or food conversion efficiency, etc.
Direct microscopy	Bright-field, phase contrast or dark-field microscopic examination of stained or unstained tissue smears, whole-mounts, wet-mounts, etc. of diseased or abnormal specimens.
Histopathology	Routine histological or histochemical (with special stains) analysis of tissue sections.
Electron Microscopy	Ultrastructural examination of tissue sections, negatively stained virus preparations, or sample surfaces.
Culture & Biochemical Identification	Routine culture and isolation of bacterial isolates on artificial media and identification using biochemical reactions on unique substrates.
Enhancement	Rearing samples of the appropriate life stages of shrimp under controlled, stressful conditions to "enhance" expression of latent or low grade infections.
Bioassay	Exposure of susceptible, indicator shrimp to presumed carriers of a pathogenic agent.
Antibody-based Methods	Use of specific antibodies as diagnostic reagents in immunoblot, immunohisotchemistry, agglutination, IFAT, ELISA, or other tests.
Hematology & Clinical Chemistry	Determination of hemocyte differential count, hemolymph clotting time, glucose, lactic acid, fatty acids, certain enzymes, etc.
Toxicology/Analysis	Detection of toxicants by analysis and verification of toxicity by bioassay.
DNA Probes	Detection of unique portions of a pathogen's nucleic acid using a labeled DNA probe.
PCR/RT-PCR	Amplification of unique sections of a pathogen's genome to readily detectable concentrations using specific primer pairs.
Tissue Culture	*In vitro* culture of shrimp pathogens in non-shrimp tissue culture systems or in primary cell cultures derived from shrimp.

Table 4
Viruses of Penaeid Shrimp (as of December 2000; modified from Lightner 1996, 2000; Lightner and Redman 1998).

Family Group/Acronym/ Full Name	Key References
PARVOVIRUSES (Parvoviridae): IHHNV = infectious hypodermal and hematopoietic necrosis virus HPV = hepatopancreatic parvovirus SMV = spawner-isolated mortality virus LPV = lymphoidal parvo-like virus	Lightner et al. 1983a,b Bonami et al. 1990 Lightner & Redman 1985 Fraser & Owens 1996 Owens et al. 1991
BACULOVIRUSES and BACULO-LIKE VIRUSES: BP-type = *Baculovirus penaei* type viruses (PvSNPV type sp.): BP strains from the Gulf of Mexico, Hawaii & Eastern Pacific MBV-type = *Penaeus monodon*-type baculoviruses (PmSNPV type sp.): MBV strains from East and South east Asia and the Indo-pacific BMN-type = baculoviral midgut gland necrosis type viruses: BMN = from *P. japonicus* in Japan TCBV = type C baculovirus of *P. monodon* PHRV = hemocyte-infecting non-occluded baculo-like virus	Couch 1974a, 1974b Bonami et al. 1995 Brock et al. 1986 Lightner et al. 1983c Wang et al. 1996 Momoyama & Sano 1996 Arimoto et al. 1995 Mari et al. 1993 Chang et al. 1993 Owens 1993
WHITE SPOT SYNDROME VIRUSES (Nimaviridae): SEMBV = Systemic ectodermal & mesodermal baculo-like virus RV-PJ = rod shaped virus of *P. japonicus* PAV = penaeid acute viremia virus	Wongteerasupaya et al. 1995a Takahashi et al. 1994, 1996 Huang et al. 1995 Wang et al. 1995, 1998 Lo et al. 1996, 1997, 1999 Durand et al. 1996, 1997 Chou et al. 1995

HHNB = hypodermal & hematopoietic necrosis baculo-like virus; agent of "SEEDS" (shrimp explosive epidermic disease) WSBV = white spot baculo-like virus PRDV = penaeid rod-shaped DNA virus WSSV = white spot syndrome virus WSV = white spot virus	Kimura et al. 1996 Kasornchandra et al. 1998 van Hulten et al. 2000
IRIDOVIRUS: IRIDO = shrimp iridovirus	Lightner and Redman 1993
RNA VIRUSES	
PICORNAVIRUS (Picornaviridae): TSV = Taura syndrome virus	Lightner et al. 1995 Brock et al. 1995, 1997 Hasson et al. 1995 Bonami et al. 1997 Mari et al. 1998 Nunan et al. 1998
REOVIRUSES: REO-III & IV = reo-like virus type II and IV	Tsing & Bonami 1987 Adams & Bonami 1991
TOGA-LIKE VIRUS: Lymphoid organ vacuolization virus	Bonami et al. 1992 Lightner 1996
RHABDOVIRUS: Rhabdo virus of penaeid shrimp	Nadala et al. 1992 Lu & Loh 1994
YELLOW HEAD VIRUS GROUP: YHV/"YBV" = yellow head virus of *P. monodon* GAV = gill associated virus of *P. monodon* LOV = lymphoid organ virus of *P. monodon*	Chantanachookin et al. 1993 Boonyaratpalin et al. 1993 Wongteerasupaya et al. 95b, 97 Tang & Lightner 1999 Flegel et al. 1995 Spann et al. 1995, 97

Table 5.
OIE notifiable and listed penaeid shrimp diseases and their current, presently known distribution in wild and cultured stocks (modified from Lightner 1996; Lightner and Redman 1998; OIE 2000).

Virus or Virus Group	Eastern Hemisphere	Western Hemisphere
OIE Viruses of Penaeid Shrimp:		
WSSV	wild & cultured	wild & cultured
YHV	wild & cultured	not reported
TSV	cultured	wild & cultured
OIE Listed Viruses of Penaeid Shrimp:		
IHHNV	wild & cultured	wild & cultured
BP	not reported	wild & cultured
MBV	wild & cultured	reported; not enzootic
BMN	wild & cultured	not reported
SMV	cultured	not reported

Table 6
Diagnostic and pathogen detection methods for the OIE notifiable and listed viral diseases of penaeid shrimp (modified from Lightner 1996, 2000; Lightner and Redman 1998).

Method*	WSSV	IHHNV	BP	MBV	BMN	SMV	YHV-group	TSV
Direct BF / LM / PH / DF	++	-	+++	+++	++	-	++	+
Histopathology	++	++	++	++	++	++	+++	+++
Bioassay	++	+	+	-	+	-	+	++
TEM / SEM	+	+	+	+	+	++	+	+
ELISA with PAb / Mab	-	-	+	-	+	-	-	++
DNA Probes DBH / ISH	+++	+++	++	++	++	+++	+++	+++
PCR / RT-PCR	+++	+++	+++	+	-	+++	+++	+++

- **Definitions for each virus:**

o = no known or published application of technique.

\+ = application of technique known or published, but not commonly practiced or readily available.

++ = application of technique considered by authors of present paper to provide sufficient diagnostic accuracy or pathogen detection sensitivity for most applications.

+++ = technique provides a high degree of sensitivity in pathogen detection.

Methods:

BF = bright field LM of tissue impression smears, wet?mounts, stained whole mounts;

LM = light microscopy;

PH = phase microscopy

DF = dark-field microscopy

EM = electron microscopy of sections or of purified or semi-purified virus;

ELISA = enzyme?linked immunosorbent assay;

PAbs = polyclonal antibodies;

MAbs = monoclonal antibodies;

DBH = dot blot hybridization

ISH = in situ hybridization

Table 7.
Summary of methods for surveillance and diagnosis of OIE Notifiable and Listed penaeid shrimp viral pathogens.

AGENT	SURVEILLANCE	DIAGNOSIS
TSV	RT-PCR	RT-PCR, DNA probes, AB, histology
WSSV	PCR, AB	PCR, DNA probes, AB, histology, bioassay
YHV	RT-PCR	RT-PCR, DNA probes, AB, histology, bioassay
BMN	Histology	Direct microscopy, histology
BP/MBV	PCR, direct microscopy, histology	Direct microscopy, histology, PCR
IHHNV	PCR, DNA probes	PCR, DNA probes, histology
SMV	DNA probes	DNA probes, histology, bioassay

Table 8.
Commercially available molecular and antibody-based diagnostic products for penaeid shrimp pathogens and their applications*.

Pathogen	**DNA-based Tests**			**Antibody-based Tests**	
	Dot Blot	**In Situ**	**PCR**	**Immuno Dot**	**Immuno-histochemistry**
WSSV	X	X	X	X	X
IHHNV	X	X	X		
TSV	X	X	X	X	X
HPV	X	X	X		
MBV	X	X	X		
BP	X	X	X		
YHV	X	X	X		
NHP bacterium	X	X	X		

** Available from DiagXotics, Inc. Wilton, CT, USA*

8

FARM-RAISED SHRIMP GOOD AQUACULTURE PRACTICES FOR PRODUCT QUALITY AND SAFETY

FARM-RAISED SHRIMP GOOD AQUACULTURE PRACTICES FOR PRODUCT QUALITY AND SAFETY

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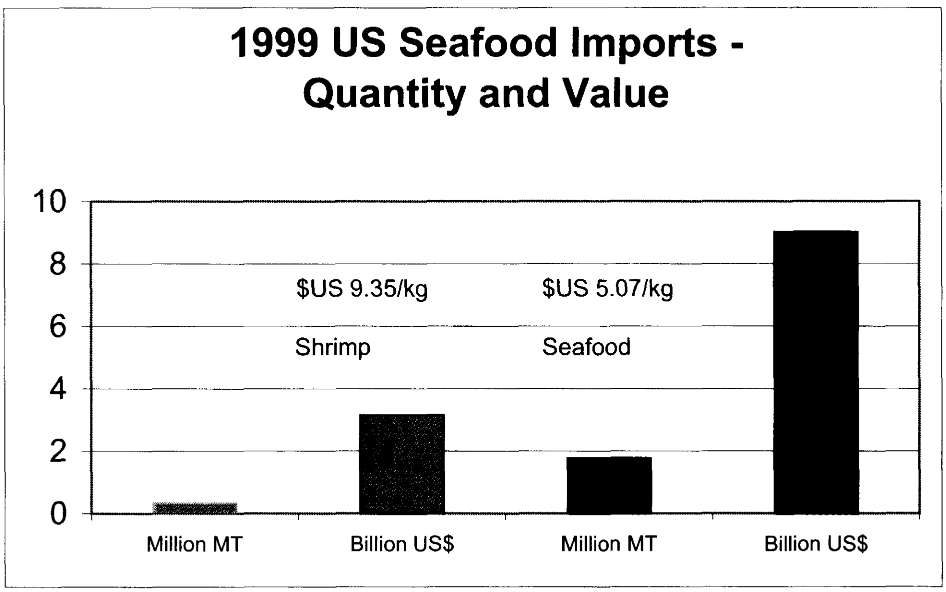
IMPORTANCE OF PRODUCT SAFETY AND QUALITY

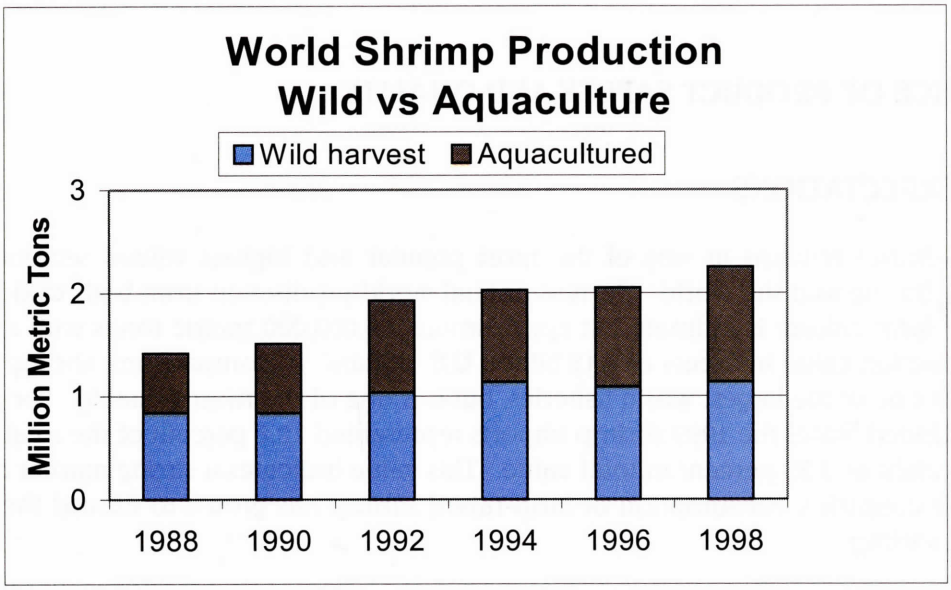
MARKET EXPECTATIONS

Shrimp remains as one of the most popular and highest valued seafood selections throughout the world. Current annual world production from both wild harvest and farm culture is estimated at approximately 3,000,000 metric tones with an estimated production value in excess of $12 billion U.S. dollars. In comparisons, shrimp production is not one of the largest world fisheries, but it is one of the most valuable. For example, in the United States the 1999 shrimp imports represented 18.8 percent of the total US imports by weight and 35 percent in total value. This value indicates a strong market demand. In some countries, consumption of farm-raised shrimp has grown to exceed the amount of wild shrimp.

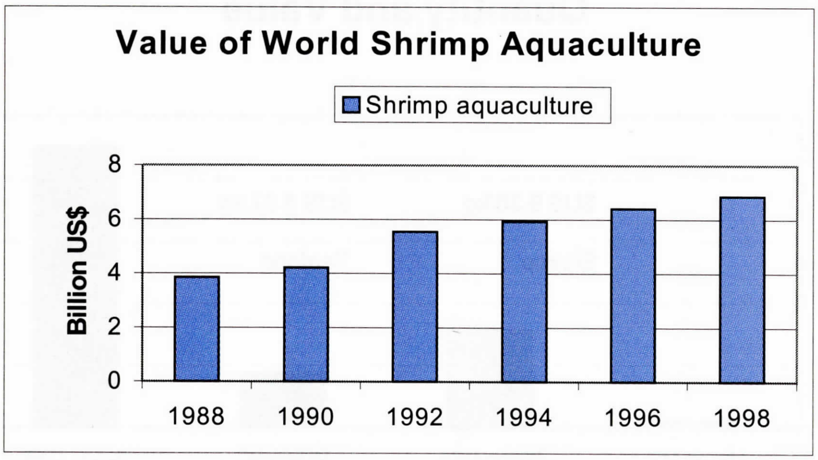


Source: WWW.NMFS.GOV , Foreign Trade data, 2001

While most world fisheries are experiencing maximum sustainable production or near overfishing, shrimp production can continue to increase through aquaculture farm operations. Shrimp aquaculture keeps growing steadily despite the adverse conditions and new challenges faced by the farmers. In 1988, farmed-raised shrimp represented 40.6 percent of the total shrimp production worldwide, increasing to 49.4 percent in 1998.



Source: WWW.FAO.ORG FishStat Plus 2000



Source: WWW.FAO.ORG FishStat Plus 2000

The growth of shrimp farming assures a positive future for the world shrimp supply, but this new industry is rapidly changing with expansion into more countries, by increasing use of more intensive farming, and through use of formulated feeds. Traditional food markets are usually suspect for a new source and new method of food production. Continuing demand and value for new shrimp products will depend on consistent product quality and safety. Market concerns include:

- Is the new shrimp as good as or better than the traditional shrimp?
- Does it taste and smell the same?
- Does it look the same, raw or cooked?
- Does it cook the same?
- Does it have the same shelf-life, when fresh or frozen?
- Is the new shrimp safe to eat?
- Does harvest and processing cause contamination with chemicals?
- Does harvesting and processing cause contamination with pathogenic bacteria?
- Do farmed animal illnesses (i.e., viruses) cause human illnesses?
- Do the farmers and processors practice good basic sanitation, hygiene and food safety standards (HACCP)?

These are reasonable and expected market questions for all foods, but the answers to these questions are becoming more difficult as the food supply becomes more distant and global. In fact, the ability to answer these questions has become a marketing advantage. This competition involves:

- farmed vs. wild shrimp supplies;
- country vs. country shrimp supplies; and
- farm vs. farm shrimp supplies.

In addition to the requirements for daily shrimp production, farmers must realize that the demand and value of their shrimp will depend on the product quality and safety.

"SHRIMP SAFETY & QUALITY = VALUE"

IMPORTANCE OF PRODUCT SAFETY AND QUALITY

REGULATORY EXPECTATIONS

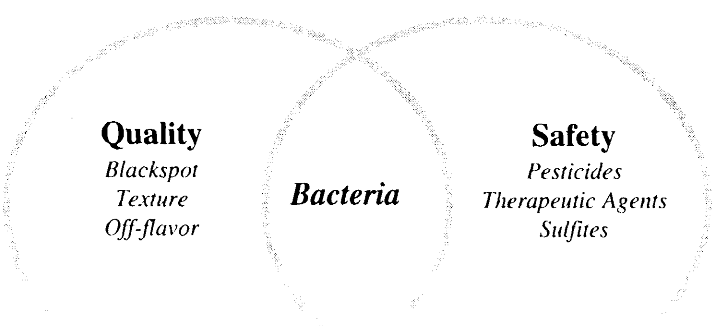
Shrimp farmers must be aware of the current regulatory expectations in their country and in the countries where their shrimp will be sold and consumed. The regulatory authorities in most nations are assigned to protect the 'safety' of their consumers. Most countries have specific regulations to assure food safety for products produced in or imported into the country. In many instances, these food safety regulations also involve or influence product quality. Regulatory expectations will be based on judgments and measures for both shrimp safety and quality.

Shrimp quality and safety are closely related. A shrimp with poor quality due to bacterial spoilage could be considered safe to eat if it is cooked to eliminate any safety concerns, but the poor quality is often considered an indirect measure for product safety. Likewise, an apparently good quality shrimp could cause illness if it is contaminated with a potential food hazard that is not obvious based on quality judgments. Regulatory authorities should try to distinguish certain safety problems. Farmed shrimp could be unsafe to eat if :

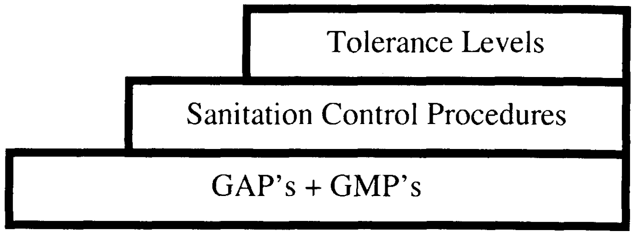
- the shrimp are contaminated with certain types or amounts of 'pathogenic' bacterial;
- the shrimp contains excessive amounts of food additives or improper food additives;
- the shrimp contains pesticides, herbicides or other potential toxic chemicals introduced during pond culture; or
- the shrimp contains improper amounts or type of therapeutic chemicals used during pond culture.

Areas of concern for shrimp quality and safety

The traditional regulatory approach has been to set various guidelines or tolerances that assure a safe product. These standards are usually enforced by inspection of products after they are processed, combined with occasional inspections of the processing facilities to enforce good manufacture practices (Appendix: GMP's). The GMP's include some basic sanitation requirements that are usually designed for processing. Good aquacultural practices (GAP's) are introduced to include farming activities linked with processing.

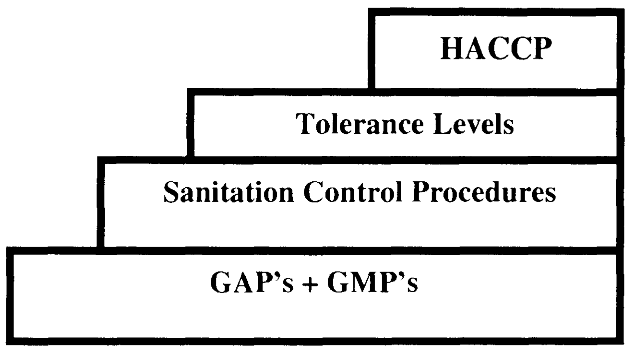


Traditional steps to food safety



As with market expectations, regulatory authorities are usually more concerned with new sources or methods of production for most foods. This concern has been most recently demonstrated by many nations adding food safety requirements based on Hazard Analysis and Critical Control Point (HACCP) programs. These requirements place more attention on 'prevention' of potential food safety problems before they occur rather than the traditional approach of inspecting or trying to find problems after they have occurred. The HACCP approach does not replace the traditional regulatory approach. It is in addition to the traditional approach and depends on a solid foundation of sanitation, and the GMP's and GAP's.

Current steps to food safety



The HACCP programs add requirements to document or record routine practices during the farm production and later processing of the shrimp. These records are the evidence that proper hygiene and sanitation control procedures have been used when growing, harvesting and processing the shrimp. The key HACCP feature is monitoring of certain 'critical control points' to maintain specified limits that assure the shrimp are safe to eat.

Typical HACCP records for farmed raised shrimp can include:

1. Therapeutic Agents Application Record (see Appendix 4)
2. Feed / Weight Control Record (see Appendix 4)
3. Pre-Harvest Product Evaluation Record (see Appendix 4)

The traditional and new regulatory expectations realize that shrimp product safety begins in the pond. Farmers can no longer depend on the processor to eliminate or reduce potential problems. Farmers and processors must work together to maintain the quality and safety of the shrimp during culture, harvest, processing and distribution to markets.

SHRIMP QUALITY & SAFETY = ACCEPTANCE

FOOD QUALITY CONCERNS FOR FARMED SHRIMP

Shrimp quality is essential to maintaining product value. Poor quality cannot only reduce value, but could build a poor reputation for a particular farm, processor or an entire country. As for product safety, certain controls must be used to maintain quality. The following list of problems and controls is based on industry experiences, buyer specifications and some related regulations for shrimp produced and sold about the world.

Quality Concerns	Defects	Preventative Measures
Appearance	Blackspot	Proper application of sulfite or Everfresh
	Broken & damaged	Proper handling and icing
	Heat discoloration	Timely placement of product in ice
	Loose heads (whole product)	Proper handling of product in ice only
	Red heads	Stop feeding 48 hrs before harvest.
	Soft Shell (Whole and Shell-on product)	Harvest at the proper time based on periodic checks
	Yellowing	Proper use of sulfites
	Pitted or gritty shells	Proper use of sulfites
	Milky shrimp	Culling from the harvest
	Mixed Species	Separation by species at the plant
Odor / Flavor	Decomposition	Timely placement of product in ice
	Chlorine	Use proper concentration & exposure time
	Petro-chemical smell	Prevent contamination with oil, diesel, etc
	Choclo / Earthy Smell	Sensory test before harvest
	Off-flavors in the head	Sensory test before harvest
Texture	Mushy and /or soft texture	Proper shrimp to ice ratio and timely placement of product in ice
Processing Defects	Short weight	Routine checks for proper specifications
	Off-counts	
	Uniformity	
	Dehydration	Proper glazing
	Extraneous materials	Proper culling

"CONTROLS ARE REQUIRED TO PREVENT, ELIMINATE OR REDUCE QUALITY PROBLEMS"

FOOD SAFETY CONCERNS FOR FARMED SHRIMP

Shrimp remains one of the safest sources of seafood in the world. Food safety problems are rare, but certain problems can result in significant illnesses and costly damage to the industry and product reputation. The following list of potential food safety problems is based on actual market experiences and scientific evidence that indicate these problems are 'reasonably likely to occur' for farmed shrimp. All of these problems can be eliminated or reduced with appropriate controls.

Food Safety Concerns	Controls
Biological Pathogenic bacteria - *Salmonella spp.* - *Vibrio cholera* - Pathogenic *Escherichia coli*	Increase culture water exchange, use of antimicrobial agents, or divert product to value added application. Determine the contamination source and apply controls.
Chemical Pesticides - Pesticides from agriculture - Insecticides, rodenticides, & other chemicals -	Do not apply pesticides in the vicinity of the ponds or the feed. Be aware of application of these compounds in adjacent farms. Prevent contamination through run-offs.
Herbicides - Chlorphenoxy compounds - Triazine herbicides, & others	Do not apply herbicides in the vicinity of the ponds or the feed. Be aware of application of these compounds in adjacent farms. Prevent contamination through run-offs.
Fertilizers and Water Treatment Compounds - Ammonium compounds, Calcium phosphate, Phosphoric acid, Potassium chloride, Sodium silicate, Lime, hydrated lime, & limestone	Fertilizers and water treatment compounds are normally not considered to be a food safety problem. You should not apply fertilizers close to the harvest date.
Other contaminants - Heavy metals, i.e. methyl mercury	Not normally considered as a food safety concern in shrimp. Cadmium, lead and mercury are the most commonly found heavy metals in seafood products.
Therapeutic Agents - Oxytetracycline, Oxilinic acid, Furazolidone, Quinolona, & Terrivet	The use of these compounds is a major concern in shrimp aquaculture and controls are needed. The farmer needs to be aware of which product is approved or not for the country where the product will be shipped. Records need to be kept on the usage and recommended withdrawal times.
Food Additives - Sulfites	Sulfites are known to cause an allergic-type reaction for certain consumers and need to be controlled. If sulfites are used, product needs to be properly labeled.
Sanitizer residues	Proper labeling and proper use of cleaning and sanitizing compounds is essential to prevent any contamination on the product. Use proper concentrations and proper exposure time.
Physical - Debris - Filth	Filth and debris are normally considered to be a quality defect and not a food safety issue. Both of these problems need to be minimized to avoid problems at the port of entry of the receiving country. Both problems can be reduced by proper culling and sequential washes following the harvest.

MICROBIAL CONCERNS FOR FARM-RAISED SHRIMP

Bacteria and viruses are the microbial concerns associated with most seafood, including farmed shrimp. They are too small to be seen without a microscope and they are widespread throughout our environment, on our foods, and inside and on our bodies. Bacteria are by far the most common food problem, both in terms of food spoilage and contamination. Viruses can also contaminate seafood and certain varieties can harm the health and growth of farmed shrimp. Basic knowledge of these microbial concerns is essential to developing and maintaining controls to prevent food quality and food safety pro-blems.

What are bacteria?

Bacteria are living, single cell, microscopic organisms that thrive as numerous shapes and types. With reference to foods, they can be classified into two main groups - spoilage and pathogenic bacteria. The **spoilage bacteria** include types that cause foods to develop bad odors and off-flavors leading to eventual product decomposition and market rejection. The spoilage types can be further classified according to the temperature range that they can grow to cause spoilage. For example, bacteria that grow and spoil farm-raised shrimp at refrigeration (cool) temperatures (0-15°C) primarily consist of *Shewanella putrefaciens* and *Pseudomonas* spp. Microorganisms that grow and spoil farm-raised shrimp at warm temperatures (>15°C) tend to be dominated by *Vibrio* species.

Common Bacteria Associated with Shrimp	
Spoilage Bacteria	Pathogenic Bacteria
Shewanella putrefaciens	*Salmonella*
Vibrio	*V. cholerea*
Pseudomonas	Other Fecal Pathogens

Pathogenic bacteria are those that cause human illnesses. Common examples are *Salmonella*, *Vibrio cholera*, *E.coli*, *coliforms*, and *Listeria monocytogenes*. By far, *Salmonella* is the primary microbial pathogen of concern for farmed raised shrimp. This concern is not based on actual human illnesses that have resulted from contaminated shrimp, but rather certain regulations that require a "zero" tolerance or *Salmonella* free condition for shrimp products that are raw or cooked, and both fresh or frozen. The regulations consider the presence of *Salmonella* in shrimp and other fishery products as an indicatior of the lack of sanitary controls during production, harvest, and/or processing.

How do bacteria grow?

Bacteria grow by binary fission or simply splitting. This means that one bacterial cell divides into two cells, these two cells divide into four, four divide into eight, and so on (i.e. exponential growth). The time it takes one bacterial cell to divide into two cells is called the generation time. The shorter the generation time, the faster a bacterium grows. For example, if a shrimp has 10,000 cells per gram living on it and the generation time of the bacteria is 30 minutes the following situation can occur in warm temperatures.

In this example, seven generations have occurred which took 30 minutes each resulting in the bacteria increasing from 10,000/g to 1,280,000/g. The total time necessary for this to happen was 7 x 30 minutes = 210 minutes or 3.5 hours. This demonstrates how rapidly bacteria can grow on shrimp in relatively short time unless precautionary measures are taken.

What parameters affect bacterial growth?

Several factors affect bacterial growth on shrimp including:

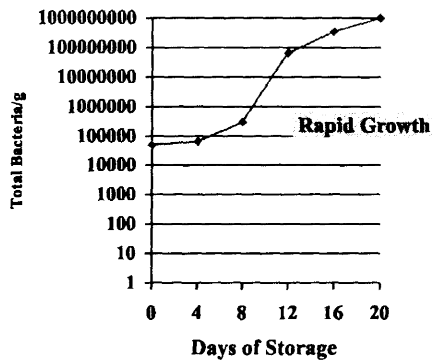
- initial amount and type of bac teria (microflora) on the shrimp;
- available nutrients (food) for growth; and
- temperature during handling and storage.

Bacterial Growth Chart

10,000/g
↓ 1 generation = 30 min
20,000/g
↓ 2 generations = 60 min
40,000/g
↓ 3 generations = 90 min
80,000/g
↓ 4 generations = 120 min
160,000/g
↓ 5 generations = 150 min
320,000/g
↓ 6 generations = 180 min
640,000/g
↓ 7 generations = 210 min
1,280,000/g

The numbers and types of bacteria initially present on the product and their specific growth requirements determine which bacteria will flourish on the product after harvest. Additionally, the nutrients for bacterial growth (i.e., energy source, water, minerals, etc.) are considered to be abundant on shrimp. Keeping in mind that microflora and ample growth nutrients are readily present on shrimp, the most important growth factor associated with producing safe, good quality shrimp is the temperature control. The greater the temperature and length of product exposure, the faster the bacteria will grow and spoil the product. In the previous example demonstrating bacterial growth by binary fission, we showed that 10,000 bacterial cells per gram increased to 1,280,000 cells per gram of shrimp in 3.5 hours under conditions where generation time was 30 minutes. If shrimp are stored at 36 °C the growth rate of the bacteria would approximate this. It takes about 12 days (288 hours) for bacteria on shrimp stored at 0 °C (ice) to increase from 10,000 cells per gram to 1,280,000 cells per gram which means that the bacteria have a generation time of approximately 41.14 hours. It can therefore be seen that storage at low temperature significantly retards bacterial growth.

Total Bacteria on Penaeid Shrimp Decomposed during Ice Storage



How do we control bacteria associated with farm-raised shrimp (pathogenic and spoilage organisms)?

First, pathogenic bacteria associated with farm-raised shrimp are mainly controlled by maintaining good pond water quality. A source of pond water with limited concentrations of pathogens will minimize the probability of harvesting product contaminated with these organisms. Likewise, control of fecal contamination (human and animal waste) at the pond site helps prevent further contamination of the pond water. Additionally, concentrations of spoilage bacteria, fecal pathogens, and other pathogenic bacteria present on farm-raised shrimp can be minimized by reducing temperature exposure through the use of clean ice. Use of anti-microbial agents (i.e., chlorine rinses) to reduce any bacteria present is a final line of defense that can be applied during harvest and processing.

What are viruses?

Viruses are defined as submicroscopic pathogens composed essentially of a core of a single nucleic acid enclosed by a protein coat. They are able to replicate only within a living cell.

What viruses are important in farm-raised shrimp (shrimp viral pathogens and human viral pathogens)?

Two groups of viruses are of concern in farm-raised shrimp, shrimp pathogens and human pathogens. Shrimp viral pathogens, like Taura, Yellowhead, and White Spot are viruses that cause disease in the shrimp. These viruses do not cause disease in humans and are not food safety concerns.

Human viral pathogens are viruses that cause disease in humans. The viruses of concern in farm-raised shrimp from a food safety perspective are Hepatitis A and E and Norwalk-Like viruses. These viruses are generally associated with fecal contamination of the product resulting from polluted growing waters and poor hygienic practices from workers handling the product. Control of viral fecal pathogens is accomplished by maintaining good pond water quality and good hygienic practices.

SHRIMP DECOMPOSITION

What is decomposition?

Decomposition is a regulatory term used to describe or measure the advancing stages of food product spoilage. Decomposition is caused by initial bacterial breakdown of the food products and the additional chemical enzyme changes that contribute to further degradation of the product. These changes are noticed and described by abnormal odors, off-flavors, textural changes, and product discoloration.

How is decomposition measured (sensory and chemical)?

Measures for decomposition in shrimp are based on sensory and chemical analyses. The main parameter evaluated in sensory analyses is the odor of the shrimp. The odor of shrimp is judged using a 3-Class system, which is described below.

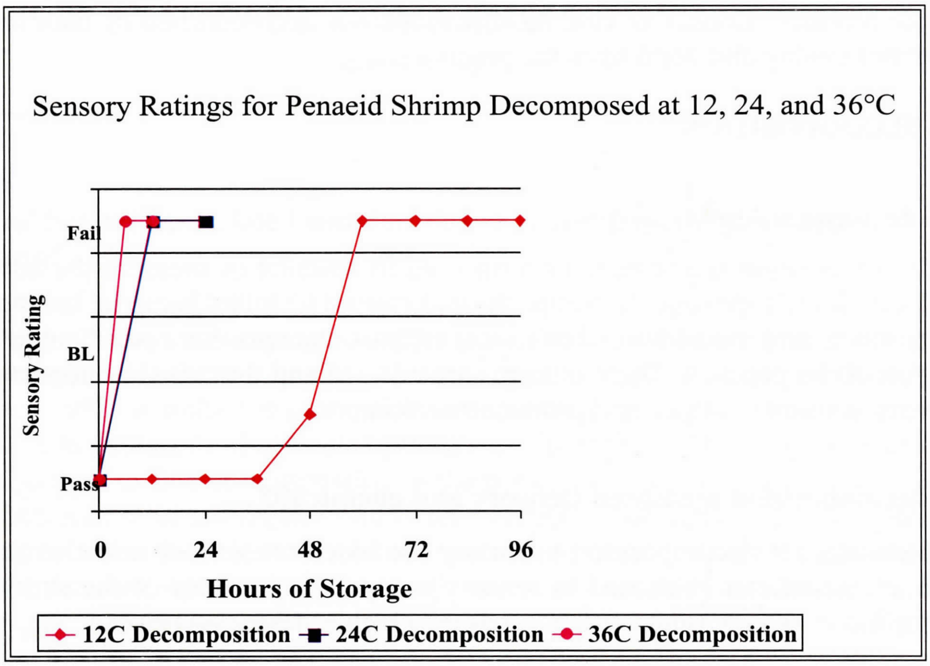
- **Class 1 - Passable**
  Includes fishery products that range from very fresh to those that contain fishy odors or others characteristic of the commercial product, not definitely identifiable as decomposition.

- **Class 2 - Decomposed (slight but definite)**
  Represents the first stage of definitely identifiable decomposition. An odor is present that, while not really intense, is persistent and readily perceptible to the experienced examiner as that of decomposition.

- **Class 3 - Decomposed (advanced)**
  Possesses a strong odor of decomposition that is persistent, distinct, and unmistakable.

Decomposition is also measured by chemical analyses for compounds that are developed during progressive spoilage. Compounds that have been most useful for analyzing shrimp decomposition are putrescine, cadaverine, and indole. Indole at the 25-mg/100g level has traditionally been used by FDA for confirmation of sensory decomposition. More recent tests indicate that other chemical indicators like putrescine or cadaverine at selected concentrations may confirm sensory decomposition more accurately than indole. Research is in progress to better understand potential applications for these indicators in regulatory and industry settings.

How long does it take for shrimp to decompose at temperatures of 12, 24 and 36 °C?



The above graph show the progressive changes in sensory classification over time for farm-raised Nicaraguan shrimp (*Litopenaeus vannamei*) decomposed at 12, 24 and 36 °C. On the graph, the lowest section indicates passable product, the middle section indicates borderline product (BL), and the top section indicates failed product, Class 2 or greater.

The shrimp decomposed at 12 °C failed sensory analysis at hour 60, the shrimp decomposed at 24 °C failed sensory analysis at hour 12, and the shrimp decomposed at 36 °C failed sensory analysis at hour 6. Sensory decomposition increased much more rapidly in the shrimp decomposed at 24 °C and 36 °C than the shrimp decomposed at 12 °C. Note, there is a similar period of rapid sensory decomposition accompanying the rapid growth period for bacterial.

FILTH IN SHRIMP

What is filth in reference to farmed shrimp?

Filth is a regulatory term referring to dirt, debris and other undesirable materials that can become mixed with a food such as shrimp. These materials can include things such as wood splinters, sticks, stones, plant stems, mud, sand, rust, burlap bagging, cigarette butts, paint chips and other items that are not considered a typical or valued part of the food. Filth found in shrimp can include insects, insect parts or fragments, rodent hairs, feathers and other objectionable animal parts that can become mixed with the shrimp during harvest and processing.

What are some typical measures for filth or foreign matter?

Samples of fresh or frozen raw shrimp may be detained when a regulatory analysis results in the following levels:

- FLIES AND OTHER INSECTS (WHOLE OR EQUIVALENT)
  1. Disease-carrying insects-2 in a sample
  2. Other insects- 3 of the same species in a sample.

- INSECT FRAGMENTS
  1. Fragments from disease-carrying insects - 5 fragments (excluding set fragments are clearly identified as parts of a disease-carrying insect)
  2. Large body parts of disease-carrying insects (i.e. head, thorax, abdomen) -1 in at least 2 of 6 subsamples*.

- HAIRS
  1. Rat or Mouse-average of 1 per sub*, any size.
  2. Striated but not rat or mouse-Average of 4 per subsample*, any size.

* sub samples are referred to as units within the original samples taken by the regulatory official.

These measures for filth are guidelines established by the FDA (Food & Drug Administration) in the United States. They are similar for authorities in Europe, Canada and other countries. Experts are trained to examine food products with direct eye observations or with the aid of microscopes. The above guidance does not include all types of filth of different combinations of filth that may be found in shrimp. The filth guidelines are considered an indirect measure for previous handling conditions that were not sanitary and could have contributed to potential foodborne illnesses.

Can filth cause illnesses if eaten with the food?

All filth is undesirable in food and certain types can cause foodborne illnesses. Obviously paint chips, wood fragments and glass pieces can be harmful. Likewise, illnesses can be associated with certain disease carrying insects. Disease-carrying insects are defined as having all the following attributes:

- Wild populations known to carry *E. coli*, *Salmonella* and *Shigella*.
- Synanthropy (a preference to live in human settlements)
    1. Endophily (tendency to enter building)
    2. Communicative behavior (oscillating between filth and human food)
    3. Attraction to both human and excrement or other pathogen reservoirs.
    4. Recognition by medical entomological authorities as a disease-carrying species.

Examples include:

Flies

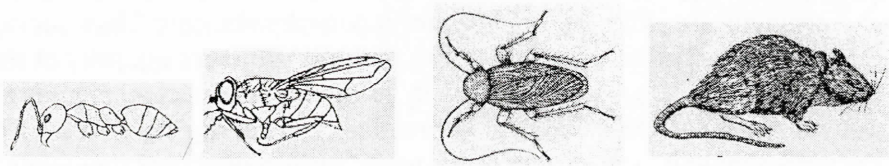
- Little house fly (*Fannia canicularies* (L.))
- Latrine fly (*Fannia scalaries* (F.))
- House fly (*Musca domestica* (L.))
- Stable fly (*Stomoxys calcitrans* (L.))
- Cosmpolitan Blue bottle fly (*Calliphora vicina* (Robineau-Desvoidy))
- Holarctic blue bottle fly (*Calliphora vomitoria* (L.))
- Oriental latrine fly (*Chrysomya megacephala* (F.))
- Blue bottle fly (*Cynomyopsis cadaverina* (R.-D.))
- Secondary screwworm (*Cochliomyia macellaria* (F.))
- Green bottle fly (*Phaeniacia sericata* (Meigen))
- Black blow fly (*Phormia regina* (Meigen))
- Redtailed flesh fly (*Sacrophaga haemorrhoidalis* (Fallen)

Ants:

- Pharaoh ant (*Monomorium pharaonis* (L.))
- Thief ant (*Solenopsis molesta* (Say))

This is not necessarily a complete list of disease-carrying insects that might be found in shrimp.

Examples of Filth:

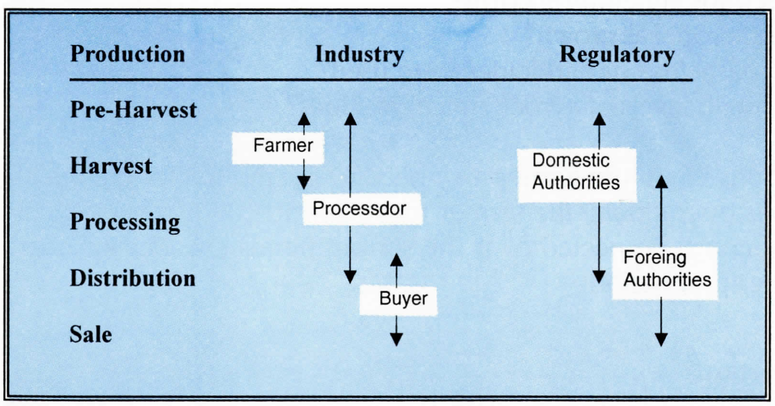


Ant **Fly** **Cockroach** **Rodent**

CONTROLLING PRODUCT QUALITY AND SAFETY

Farmers, processors and buyers share responsibility for the quality and safety of farmed shrimp. The areas of responsibility begin before harvest and continue during product distribution. Proper controls are required during shrimp growth, pond harvest, processing, distribution and storage. Due to market and regulatory expectations, the processor usually assumes continuous responsibility from production to final sale. Farmers should work with the processor to assure proper controls are used during grow-out, pre-harvest preparations and harvest operations.

Areas for Responsible Controls



Likewise, regulatory authorities in the country where the shrimp are farmed are expected to serve as a "competent authority" or third party providing surveillance and assurances that the shrimp are produced and processed to provide safe products for domestic and foreign consumption. The authority and how it is used should support the shrimp farming industry and provide information that will attract and build buyer confidence. Farmers and processors should work in cooperation with these authorities to assure the market value for their shrimp.

PRE-HARVEST CONTROLS

Pond grow-out conditions can have the most significant influence on the final product quality and safety for farmed shrimp. Quality is usually best at the moment of harvest and the methods for processing and distribution are designed to maintain the initial harvest quality. Although the product form and appearance can be changed, it ranges from difficult to impossible to improve product quality after harvest. Likewise, it is difficult to improve product safety after harvest. Methods can be used to decrease harmful bacteria or reduce chemical contaminants, but these methods require additional processing costs, and the products are still subject to further regulatory scrutiny. Thus successful shrimp farming depends on far more than simply producing a sufficient quantity of shrimp. Initial harvest quality and safety has a strong influences on processing cost, regulatory approval and market acceptance. Observing good practices before, during and after harvest are the most cost-efficient and certain way to produce shrimp of acceptable quality.

POND CARE

Location

What has been the historical use of the land?

Prior uses of the land for the pond site plays an important role in the chemical quality of the soil. If the shrimp farm is developed on land previously used for agricultural farming, accumulation of pesticides or herbicide residues could affect the growth and proper development of the shrimp and safety of the final products. Prior to building a shrimp farm the farmer needs to know the following:

- Was the land used for agricultural corps?
- What agricultural crop was grown?
- What fertilizers, pesticides or herbicides were used?
- Does the soil contain levels of agrochemical residues?

To answer some of these questions the future farmer may need to test the soil for chemical contaminants. After the farm is operational, the farmer may need to conduct periodical chemical analysis if contamination is suspected or if the shrimp ponds are located near agricultural land currently under production

Why is the location of the farm important?

Shrimp farms can be impacted by their surroundings, through the water supply, direct contact with animals, or airborne contamination (i.e. chemical sprays). Occasionally, the farms

Agricultural activities can affect shrimp farming by irrigation, rainwater run-offs and pesticide spraying.

are located near potential contamination sources, such as active livestock farms or any other industrial or sewage effluents. If the farm is located near an active agricultural or livestock farm or a community or settlement, farmers may need to monitor the impact of these activities. Agricultural lands that use pesticides and heavy fertilization on a regular basis could adversely impact the growth and the safety of the farm-raised animal. There are potential human health hazards associated with consumption of foods harvested from waters with chemical contamination. The risk for illnesses associated with these products is usually very low and requires more long-term exposures, but it remains a food safety problem that must be controlled. The farmer should try to learn:

- **WHAT** type of chemicals are used?
- **WHEN** are the chemicals applied; and
- **HOW** are the chemicals applied?

Livestock farms or sewage effluents can be a serious source of contamination by microbial pathogens (i.e. *Salmonella*, viruses, etc.). Shrimp farms need to be located away from any of these activities to decrease the chances of potential contamination. Again the farmer needs to learn :

Livestock can influence pathogen levels in shrimp ponds.

- **WHAT** type of contamination could flow from the livestock?
- **WHEN** is the livestock operation most active; and
- **HOW** could the contaminants reach the shrimp ponds?

The answers to these questions may indicate how often a farmer may need to sample ponds for chemical and microbial residues. Normal processing or cooking does not always eliminate all potential chemical and microbial contaminants associated with any previous farm site use or farming location.

> "Processing and cooking does not always eliminate potential chemical and microbial food hazards"

What type of chemical tests should a farmer conduct? When? How?

Most farmers and smaller farming operations are not expected to conduct their own chemical analysis of the pond soil, water or shrimp beyond routine water quality monitoring (Chapter 1). Tests for heavy metals, pesticides and other chemical contaminants are not routinely measured on most farms. These tests can be complicated, expensive and usually require special equipment and labs. Since a large variety of potentially harmful chemicals could be present, a wide range of tests might be necessary. The tests are usually run by a cooperating government lab or a private lab. In either lab, the tests must be conducted by recognized standard procedures. Farmers are must be familiar enough with the required tests and their protocols to determine if the proper tests are being conducted according to official, recognized methods (see Appendix 5: Regulatory Tolerances).

A reasonable approach is to first decide if a particular type of chemical could be present, then try to estimate the possibility that the residue could be in the water. Document any evidence that supports the conclusion that a contaminant may or may not be present. Evidence could be that :

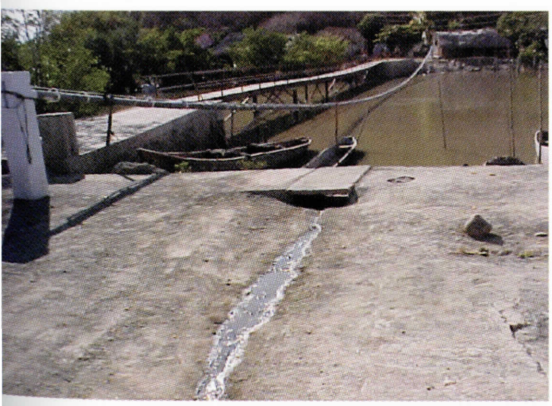
- there are no agricultural activities near the shrimp ponds;
- there is no drainage or water connecting local agricultural activities to the shrimp ponds; or
- there is no chemical spray near the shrimp ponds.

For most shrimp farms the conclusion will be that "there is no evidence to suspect potential hazardous chemicals in the pond waters or shrimp". If there is evidence, such as obvious drainage from agricultural lands or crop spraying near the ponds, then sample testing should be conducted for the water and shrimp. Sampling should be done as often as necessary, but at least once per shrimp crop. It is recommended to initially sample the water before shrimp growth to detect potential problems. A final sampling of the shrimp should be conducted prior to harvest. Allow 2 to 4 weeks for the test results depending on the analytical procedures and lab. The expense and aggravation of chemical testing is usually shared with the eventual processor. It is best to arrange government support through universities and local agencies.

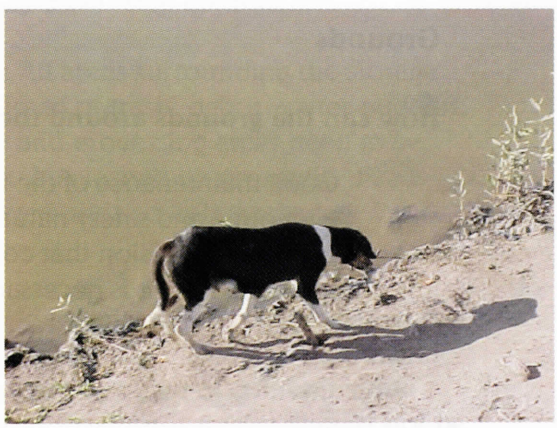
What type of microbial tests should a farmer conduct? When? How?

As for chemical residues, there should first be evidence that microbial contamination is possible. The evidence should be documented regarding possible:

- contaminated water could be entering the ponds from local rivers, lakes or other natural sources;
- drainage from a neighboring livestock operations into the shrimp ponds;
- livestock (pigs, cows, ducks, etc.) having access to the shrimp pond waters;
- human waste or sewage is reaching the shrimp ponds due to direct contact or drainage from an outhouse or local toilets; or
- human or animal defecation into or near the shrimp ponds.



Human waste (sewage) and animals, wild and domestic, are an important factor when reducing the microbial contamination in the estuaries and ponds.



If these situations are not evident, the farmer's conclusion may be that there is no evidence to suspect potential microbial hazards in the pond waters or shrimp. Unfortunately, potential microbial contamination from natural sources (local rivers, pests and wildlife) are usually evident for many shrimp farming operations. Test results for farmed shrimp from around the world support this conclusion. It is difficult to prevent this natural contamination. For these reasons, sampling for microbial tests is recommended.

Sampling is recommended as often as necessary based on the evidence, but at least once per shrimp crop. Sampling should be conducted before harvest. The test results usually require 2 to 10 days depending on the test procedures and lab. If the results indicate certain microbial contamination, the farmer and processor must consider corrective procedures. Resampling and testing are recommended to demonstrate if the corrective measure were effective.

WATER

Why is pond water quality important in aquaculture?

The water quality in the aquaculture ponds plays an essential part in the health, quality and safety of the aquaculture products. Contaminated pond water could lead to death of the shrimp, stress to reduce growth, or residues in the edible portion of the shrimp that could lead to human illness. See Chapter 1 for more information on water quality. The source of water used should always be questioned. The fresh and more brackish water sources (rivers, wells, neighboring ponds, etc) are more likely to be contaminated from the surrounding land and developments. If water quality is suspect, farmers should consider methods to control the amount of chemical and microbial contamination. Options include the volume and frequency of water exchange or the use of closed systems. The costs and consequences of these methods could influence the success of the farm.

Grounds

How can the grounds around the shrimp ponds affect product safety?

Good maintenance of the farm grounds can help reduce or eliminate many problems of an economic and safety nature. By keeping plants around the ponds (i.e. mangroves) farmers can reduce erosion that could carry chemical and microbial contaminants to the pond. At the same time it is necessary to keep the grounds clean of high, excessive weeds, and trash and debris that can attract pests.

- Erosion can carry chemical and microbial contamination
- Weeds, trash and debris can attract harmful pests.

How can pests affect the safety of the shrimp?

It is a great challenge for the farmer to develop effective controls for wild animals on the farm. Rodents (rat, mice, nutria), birds (ducks and cormorants), and other wild animals can be a source of microbial contamination (i.e. *Salmonella*). Seasonal flying species (ducks or seagulls) or terrestrial animals (rodents) need to be restricted from coming in contact with the ponds, feed or shrimp. By defecating in or around ponds or storage areas, microbial contaminants can get in the water and feeds and eventually into the shrimp. These contaminations could be carried through the processing and handling steps and consequently cause illness in consumers. Rodents are carriers of disease causing organisms and if not controlled properly, they could contaminate feeds. Rodent control around storage areas and preparation areas is essential.

Trash and solid wastes can attract rodents.

Birds can carry microbial concerns to the pond as well as cause an economic problem by preying on shrimp. Traditionally, birds have been controlled by placing nets or wires over small ponds or by using loud noises or dogs for larger ponds. If dogs are used they could be a sources of fecal material introducing microbial contamination to the ponds.

How to control rodents and similar pests on the grounds?

The incidence of rodents on the farm can be reduced by a two-step approach:

1. **Eliminate attractive food and shelter.** All areas surrounding the storage areas and processing areas need to be freed of trash, debris, water puddles, high weeds and vegetation. All storage and processing areas need to be cleaned regularly. Trash and spills must be cleaned up promptly. Feeds should be stored so that they are protected and securely packaged.

2. **Institute a pest control program.** Traps and bait systems or fumigation pro grams can be used throughout buildings, always being careful that they do not become an attractant to pests or present a source of contamination source to feed or the product. Traps or fumigation activities should not be

placed or conducted on or near shrimp products, packaging materials, feed or utensils used during harvest or handling or the shrimp. Be aware that these chemicals, if not properly used and stored, they could become a source of contamination for the aquaculture animals and even lethal for the person applying them.. Any personnel handling toxic materials should wear appropriate protective clothing (e.g. goggles, gloves, masks, as needed). Materials used for pest control should come with manufacturer's instructions and safety data sheets. Close attention should be paid to these. Pest control chemicals needs to be:

- purchased from reputable dealers
- properly labeled; and
- used in the proper manner

Original Container Label should include:	***Working Container Label should include:***
- Manufacturer / Distributor's Name - Manufacturer / Distributor's Address - Compound (Active Ingredients) - Usage Instructions - Disposal Instructions	- Compound (Active Ingredients) - Usage Instructions

Hygienic practices

Hygienic practices on the shrimp farm involve controls for potential microbial pathogens from human activities or from use of animal wastes (manure) as fertilizer. The major concern is that waste materials or fecal matter from mammals or warm-blooded animals can carry potential hazardous microbial pathogens which can be spread to the shrimp.

Potential Microbial Pathogens from Human and Animal Wastes		
Type	**Possible Illnesses**	**Source**
Salmonella	Gastroenteritis	Human waste, animal, bird and reptile manure
E. coli	Gastroenteritis	Human waste, animal, bird and reptile manure
Virus	Gastroenteritis	Human waste

How can farmers control human waste problems?

Good hygienic practices in the pond area can minimize fecal contamination of pond water. Farm personnel should not be allowed to defecate in the estuary, ponds, on the ground near the estuary or ponds, or anywhere that rain would wash the feces into the estuary or ponds. Fecal pollution in remote areas without toilets, plumbing or clean running water requires special measures. Human wastes should be handled in a way so as to prevent leakage into or contact with the pond water. This can be accomplished by allowing defecation in designated receptacles (i.e. plastic buckets), latrines, or field toilets that are subsequently treated with disinfectant (lime or chlorine) and with waste disposed of in a sanitary manner. Sanitary facilities should be located away from ponds or source water, and should be regularly maintained to prevent potential leakage into ponds or source water. Another way to dispose of disinfected human waste is to burn the excrement in a designated burning receptacle.

Can farmers fertilizers the ponds with organic materials (i.e. manure)?

Although it is not recommended, some old farming methods have used organic fertilizers during pond preparation and after ponds have been stocked with shrimp to promote primary productivity. These practices can have adverse consequences for shrimp quality and safety. For example, untreated or improperly cured manure can be a source of microbial pathogens. Use of manure as fertilizer during the pond preparation should be avoided since inorganic fertilizers are more efficient and do not present a safety hazard (see Chapter 5). Over use of fertilizers can also produce too much algae thereby reducing the dissolve oxygen in the water and producing off-flavors in the shrimp.

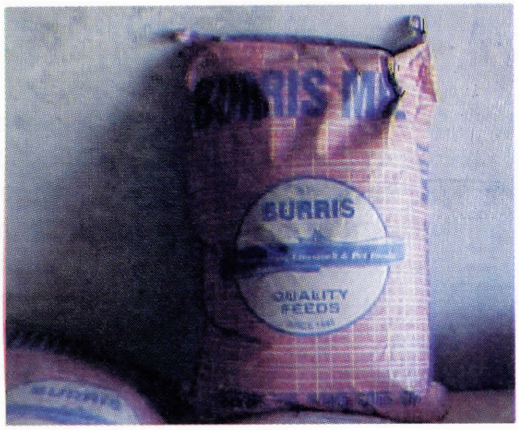
Feed care

Shrimp feeds can also cause potential food safety problems for consumers by attracting pests or through ingredients in the feed being transmitted to the shrimp.

How should I store the feed?

Feeds need to be stored in dry and cool areas to extend their shelf life. Storing the product in a wet or humid environment can result in mold formation and the development of toxic substances. Never use feeds that are molded. If the feed is stored under extreme heat or direct exposure to the sun, the nutritional quality can be reduced. Feeds containing a therapeutic agent should be well marked and separated from regular feed.

- Never accept feeds that look mishandled, wet or old.
- Feeds should be properly labeled or identified.
- Store in clean, dry, shaded, cool conditions and protect from pests.



- Do not store feeds in or near areas where they could come into contact with pesticides, herbicides, fertilizers or fuels.
- Follow the "first in and first out" rule to avoid problems with old feeds.
- Maintain an accurate inventory control and always keep new feed separated from the older feed.
- Separate regular and medicated feed (thera peutic agents).

See Chapter 4 for more information on proper feed storage and use.

Therapeutic agents

Therapeutic agents are used in shrimp and fish farming. Uses range from sex selection to the reduction or elimination of illnesses in the animals. The application of these medications or therapeutants should be be limited to extreme situations that cannot be controlled any other way. Very few shrimp diseases can be successfully treated with therapeutants, so use of these may yield little positive benefit while possibly making the shrimp unsafe for consumption. Abusive use of these compounds can also result in creation of drug resistant strains of microorganisms. Therapeutic agents should only be used by trained indivi-duals following the manufacturer's instructions and withdrawal times. The potential pro-blems associated with the use of therapeutic agents include the following:

- Allergic reactions
- Toxic effects
- Change in bacterial colonization patterns in the human-gut flora
- Development of drug resistant strains of microbial pathogens

How should farmers handle therapeutic agents?

Careful handling of these agents during application, dosage, withdrawal time, storage and disposal is extremely important to reduce the potentially negative impacts on the treated animals, farm personnel, environment and consumers. All therapeutic agents used should be recorded. An example of **Therapeutic Agents Application Record** (See Appendix 4) is designed to provide information and guidance in order to assure proper withdrawal times. This record can also aid in the investigation of potential problems.

Application of therapeutic agents is administered to shrimp feed or through dispersion in water. Certain restrictions apply depending on the drugs to be used. Always follow the recommended application levels and the withdrawal times. High levels of therapeutic agents can cause irritation or death in the animal or cause off-flavors. Maintain accurate records of application dates, dosages and the justification for use. Over use of therapeutic agents can lead to development of resistant strains of diseases and could also result in chemical residues in the edible portion of the shrimp. Strict control and records are needed when applying prescribed therapeutic agents.

Dosages should depend on the manufacturer's recommended usage levels and the method of application. Read and understand the product label.

Withdrawal time should be specified for all therapeutic agents. It is the time, usually in number of days, allowed to eliminate or reduce residuals in the shrimp. The withdrawal times will assure that the levels in the shrimp are within the permissible tolerances. New approved animal drugs have determined the proper withdrawal times for the recommended application. Withdrawal times are expressed in days (24 hrs from application). Withdrawal times normally range from 7 to 10 days after last application.

Storage, handling and disposal of the drugs or feeds contain drugs should follow the manufacturer's directions. Properly designed labels provide instructions on how to store, mix, apply and dispose of the product. Always store these products separately from food, food contact surfaces, food utensils or food packaging. Only trained personnel should handle these products. Discard all unlabeled containers. Therapeutic agents or feeds with therapeutic agents must be relabeled if they are removed from the original package.

A record should be kept of regular and medicated feed use employing the **Feed/Weight Control Record** (see an example in Appendix 4).

What therapeutic agents are approved for use with farmed shrimp?

In the United States, the Food and Drug Administration classifies therapeutic agents into three main categories: 1) approved new animal drugs; 2) unapproved animal drugs of low regulatory priority; and 3) investigational new animal drugs.

Approved New Animal Drugs are the compounds that have been approved by FDA for use with aquaculture species intended for human consumption. For Penaeid shrimp the only new approved animal drug is Formalin (Parasite-S by Western Chemical, Inc.) which is used to control protozoan parasites. The withdrawal time recommended is 10 days from the application.

Unapproved New Animal Drugs of Low Regulatory Priority are not specifically approved for aquacultural use but have not been associated with safety problems. No regulatory action is likely if the chemicals used have an appropriate grade or quality, are used at the prescribed levels, according to good management practices, and they are not likely to have an adverse effect on the environment. Examples of this type of drugs are: Acetic acid (1000-2000 ppm), Calcium chloride (up to 150 ppm in water for fish transport), Garlic (whole to control sea lice), Hydrogen peroxide (250-500 mg/L to control fungi), Magnesium sulfate (to treat monogenic trematode), and Ice (for live fish transport). Although this listing is limited and contains materials not commonly used with shrimp, it is the only approved listing. Note, farmers should always check for the chemicals allowed in the country buying the shrimp. Listed approved in the country of production or farming do not always agree with lists for the country buying the shrimp.

Investigational New Animal Drugs (INAD) are drugs that are used under an investigational permit. FDA and CVM grant the exemption permits and must be in accordance with local and state regulations.

What are extra-label drugs?

In the United States, aquaculture farmers encounter diseases for which there are no approved therapeutic drugs. In these cases, a licensed veterinarian can, under predefined criteria prescribed and use other licensed products. This practice, based on veterinarian approval, is called extra-label use.

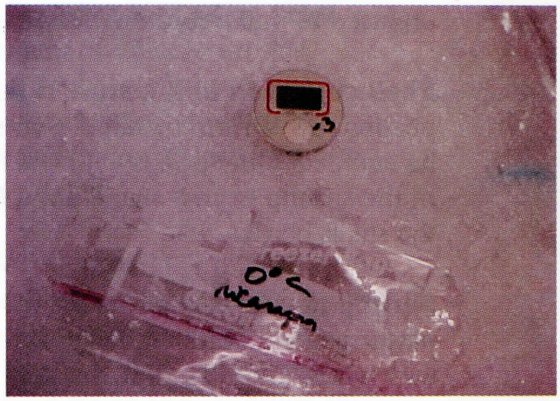
Product Evaluations (microbial and quality)

All farmers routinely monitor the size, amount and condition of their shrimp during production or pond grow-out. These routine checks can also be an excellent time to judge the quality and safety of the shrimp. It is strongly recommended that a pre-harvest check should be conducted to determine if the shrimp meet standards for product quality and safety. Once the shrimp are harvested, there is not much the farmer or processor can do to correct certain quality and safety problems. If the shrimp do not meet the standards, corrective measures applied at the ponds could help reduce the problem.

How should a farmer collect pre-harvest samples for evaluation?

Live shrimp samples (2 to 3 pounds) should be collected from different locations in the pond with a clean seine or cast net in a manner that does not drag the shrimp through pond mud or the dirt bank. The samples should be combined in a sterile container. Careful handling is necessary to prevent contamination of the samples. The sample should be transferred without debris or mud from the pond. This sample should be handled by workers with clean hands. The container should be placed immediately on ice for delivery for microbial analysis at the processing plant or designated lab. The container should be surrounded with enough ice to maintain the sample below 35 °F until it is removed for testing. If plastic bags are used, the shrimp should not puncture the bag and should not come in contact with the ice or melt water. Double bagging the shrimp may be necessary. This sample must be sent to the lab within less than 24 hours after taking the sample.

Pre-harvest sample collection



Pre-harvest sample ice storage for transportation

One portion of the sample will be used for microbial analysis. The remaining portion should be used for **quality evaluations** such as shell condition, texture, color and flavors. These measures can also be conducted pond side and at a processing lab with facilities to properly cook the shrimp for flavor and odor tests. If these evaluations are conduct a distance from the pond site, the samples should be placed and transported in a container similar to that used for the microbial sample. The evaluations must be conducted in less than 24 hours after the sample is collected. All evaluation results should be recorded in a **Pre-Harvest Evaluation Record** (See Appendix 4) at the farm/pond site or in the processing lab.

How are the evaluations conducted and problems corrected?

Pre-harvest microbial testing should screen for potential *Salmonella* based on a standard microbial procedure that requires lab facilities (see Microbial Concerns for Farmed Shrimp). The standard procedures may require 4 to 7 days to complete. In some cases, more rapid, unofficial tests can be used to provide a quicker, but less accurate measure for *Salmonella*. If the shrimp test negative (no *Salmonella* detected), then the shrimp can be harvested. If the shrimp test positive for *Salmonella*, then corrective options should be considered to reduce or eliminate the *Salmonella* from the shrimp. Since the pond water is generally considered to be the *Salmonella* source, water exchange in the pond may reduce or eliminate the organisms from the pond and/or the shrimp. If water exchange is unsuccessful, the farmer may need to work with the processor to either sell the shrimp in a market where *Salmonella* is acceptable in the raw product or to further process the product to reduce or eliminate the *Salmonella*. Further processing of the product may include heading, peeling, and deveining with subsequent antimicrobial treatments, mild treatment, complete cooking, or value-added processing with a final cook step. It is recommended that final product testing for *Salmonella* should be conducted when any of these further processing options are used to make sure the *Salmonella* has been eliminated from the product.

Shell condition and texture is determined by feeling the shell surface and strength, and peeling raw shrimp by hand. Soft shells due to recent shedding or possible disease should be avoided. Only ponds with less than 5% soft shells should be harvested. If more than 5% of the shrimp from a single pond have soft shells, the farmer should wait a few days until the shells harden.

Shrimp flavors and odors are best judged with cooked shrimp. Boiling shrimp in a sealed plastic bag is recommended to capture the odors released during cooking. A new, clean bag with whole shrimp (approximately ¼ pound or 250 grams) can be placed directly in boiling water for about 1 to 3 minutes to assure an effective test. Make sure the shrimp do not pierce the bag causing leakage. The odors will be obvious when the bag is carefully opened. Further odor judgments should be conducted after breaking segments of the cooked shrimp and shrimp heads for direct nose evaluations. The odors are usually a better indication of potential problems than is the flavor.

Only ponds with acceptable odors and flavor should be harvested. Since is difficult to eliminate certain natural off-flavors after harvest, shrimp should be maintained in the ponds until off-flavors are purged. Shrimp farmers may be able to eliminate certain algae that cause the off-flavor by increasing water pH. This has been accomplished by carefully applying lime. This treatment should be gradually done for 3 to 5 days until the increase in pH eliminates the algae. Another pond management practice is to increase the water exchange and aerate with agitators. Another sample must be taken to determine if the corrections are effective.

Therapeutic agent treatments used during the production cycle should be documented on theTherapeutic Agent Application Record (See Appendix 4). This record should be consulted before harvest to ensure that appropriate recommended withdrawal times for all therapeutants used are met. If appropriate recommended withdrawal times are not met, shrimp should be left in the pond until the required withdrawal times are met.

HARVEST CONTROLS

The farm-raised shrimp harvesting operations involve a number of steps that can influence final product quality and safety. The key steps are Reduced Feeding; Preparing Equipment, Supplies and Workers; Harvest; and Product Handling and Transport. Farmers must consider proper procedures at each step to reduce bacterial contamination and prevent product discolorations.

After the processing plant approves harvest, what does the farmer need to do to assure quality and safety of the shrimp?

- REDUCE FEEDING: Feeding should be stopped at least 48 hrs before harvesting. This will reduce the development of off-colors in the head of the shrimp known as 'red head'. The discoloration is due to food digesting in the gut (cephalothorax segment) of the shrimp. This discoloration is not a food safety or edible quality problem, but buyers have considered it to be a product defect.

- PREPARE EQUIPMENT, SUPPLIES and WORKERS: If not available on pond site, farmers should confirm that either the processing plant or product buyer is going to send enough clean potable water, clean ice, and clean containers to collect the product. As a general rule, farmers must have two pounds of ice per every pound of shrimp to be harvested or at least a pound of ice per pound of shrimp to be harvested. This will prevent spoilage problems due to lack of ice.

RECOMMENDATION
"Prefer 2 parts ice per 1 part shrimp on a weight basis"

If not available at the farm, farmers should confirm that either the processing plant or product buyer will send enough blackspot controls, sanitizing compounds and clean potable water to treat the shrimp at harvest. The amount of material needed will be based on the amount of shrimp expected to be harvested, plus some extra in case of unexpected problems or more shrimp.

It is **CRITICAL** that enough clean water (not pond or river water) is available to prepare the shrimp treatment solutions and washes (see Melanosis and Chlorination).

Clean water should comply with the chemical and microbiological contaminant levels specified by the regional authorities. These standards should be equivalent to the international drinking water standards specified by FAO/WHO.

Although the actual harvesting can be a dirty operation, the equipment used to catch the shrimp should be cleaned to remove debris and previous dead shrimp that could contaminate the new shrimp. All baskets, tubs or bins for handling and transporting the shrimp should be properly cleaned and sanitized. The 4-step cleaning procedure includes:

1. Wash with detergent
2. Rinse with clean water
3. Sanitize with 200 ppm chlorine
4. Final rinse with clean water before use

All employees that are scheduled to work during the harvest must be in good health and have no infected cuts on their hands. The best rule is to avoid any hand contact with the harvested shrimp.

How should the product be handled during and after harvest?

- **HARVEST:** On most farms the shrimp is harvested with a net or bag that catches the shrimp as the pond is drained. This process must be done with some care to prevent damage to the shrimp or excessive accumulation of mud and debris with the shrimp. The bag should be emptied into clean baskets, tubs or bins approximately every 15 to 20 minutes. Regardless of the amount harvested, the temporary storage containers should weigh no more than 50 to 60 pounds per container to allow for reasonable handling.

  Shrimp should be treated on the farm while in the temporary storage containers to prevent development of blackspot (melanosis) and to reduce potential pathogenic bacteria. The blackspot treatments (bisulfites or Everfresh) are more effective if they are applied immediately after harvest, even while the shrimp are alive. Likewise, if there are concerns about any potential pathogenic bacteria such as *Salmonella*, anti-microbial treatments to reduce these pathogens (i.e., chlorination washes) should be applied at the farm to help prevent carrying these bacteria to the processing plant. The sequence and methods for treatment will depend on the particu lar shrimp and farming location. Farmers and processors must determine the best treatment options keeping in mind that some anti-microbial treatments may influence the effectiveness of the melanosis treatment. Regardless of which treatments are used, they must be applied using clean potable water.

All shrimp treatments must be applied using clean water

- **PRODUCT HANDLING and TRANPORT**: the final ice packing of the shrimp for transport should assure proper chilling without damaging the shrimp. Shrimp packed in ice alone should be packed by layering. A layer of ice should be placed on the bottom of the tote followed by a layer of shrimp and then a layer of ice and so on. When the tote has been fully packed a final layer if ice should be placed on the top to maximize the cooling effect. When an ice slush is used, the shrimp and ice slush should be thoroughly mixed to eliminate any large pockets of shrimp from forming in the tote. Again, a final layer of ice on top of the packed tote will maximize the cooling effect.

  Shrimp that is not harvested by draining the pond should never be mixed with shrimp captured by draining. Shrimp left behind may be of lower quality; mixing these shrimp with the shrimp harvested during the initial drain may lower the value of the entire lot. Leftover or hand harvested shrimp should be placed in separate bins labeled as "handpicked" shrimp. This shrimp should be segregated and properly identified for further evaluation by the processing plant.

Shrimp must be sent to the processing plant as soon as possible.

Other considerations:

- Product should be monitored to avoid chemical contamination from generators, trucks, etc. used during the harvest.
- Farmers should try to reduce pests and insects during the harvest that could other wise cause filth contamination.
- The bins or container designated to transport shrimp from the farm to the processing plant should never be placed in contact with the ground.

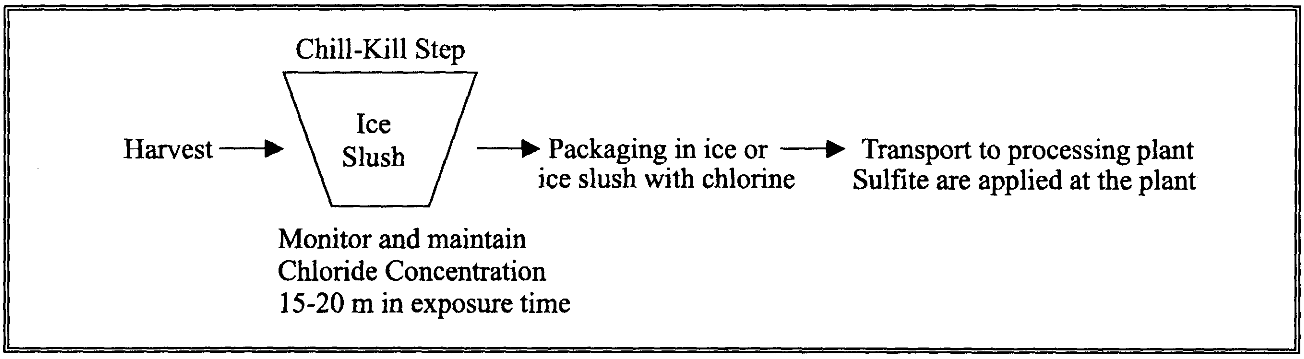
What are the recommended methods for use of chlorine and melanosis treatments?

Proper and careful use of chlorine and melanosis treatments is necessary to achieve the recognized and necessary benefits of these chemical aids. There is no single method for application. The methods for use will vary depending on the situations at the farm and processing locations, and the type of product to be processed. The best option will depend on experience with the farm and the processor.

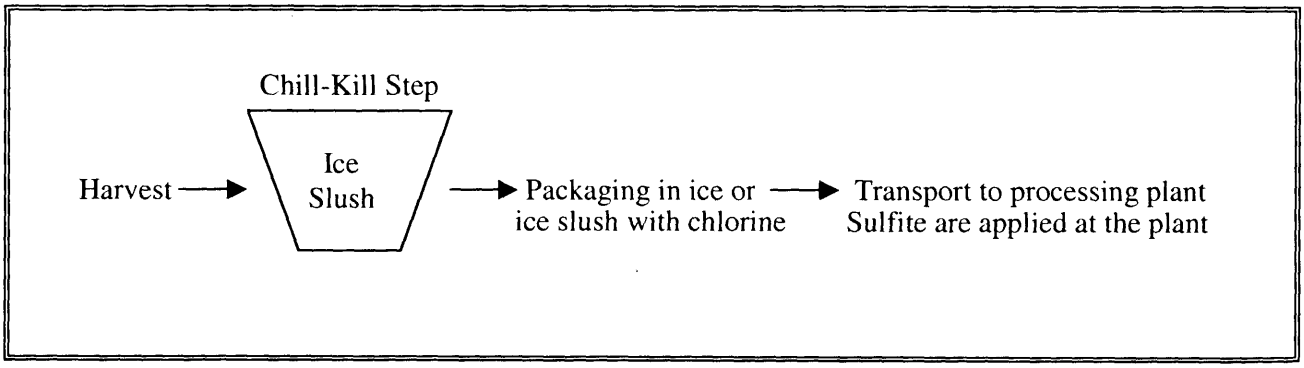
Options for product to be headless/shell-on or peeled (options A & B)

Note that these options assume the harvest is conducted close to the processing operation so that there are no delays in the delivery of the fresh shrimp. If the harvested shrimp is delayed in transport to the processing plant, the application of sulfites should be arranged near the harvesting operation.

A. More aggressive bacterial controls necessary immediately after harvest



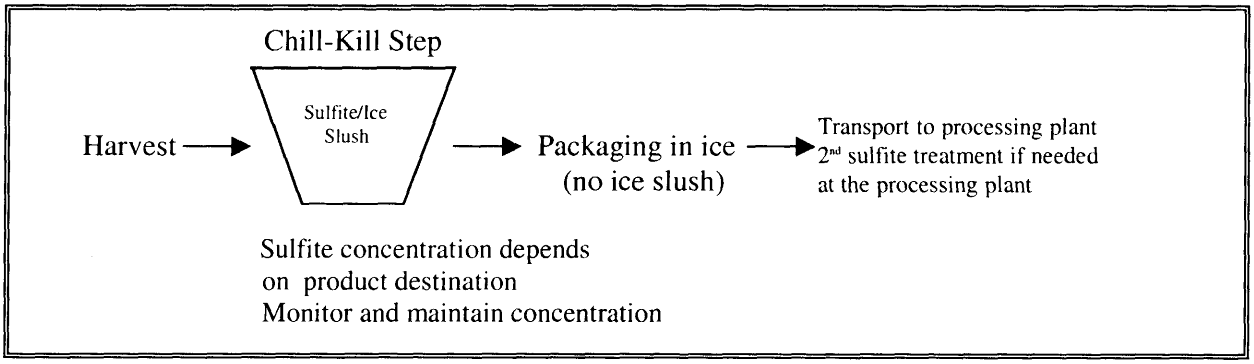
B. Mild bacterial controls may be necessary after harvest

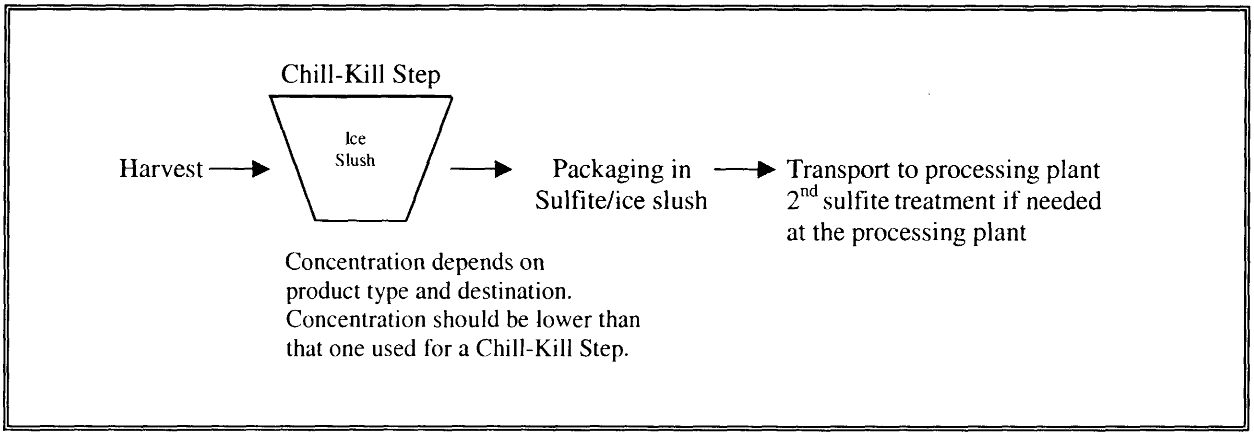


Options for product to be processed for head-on (whole) shrimp (options C & D).

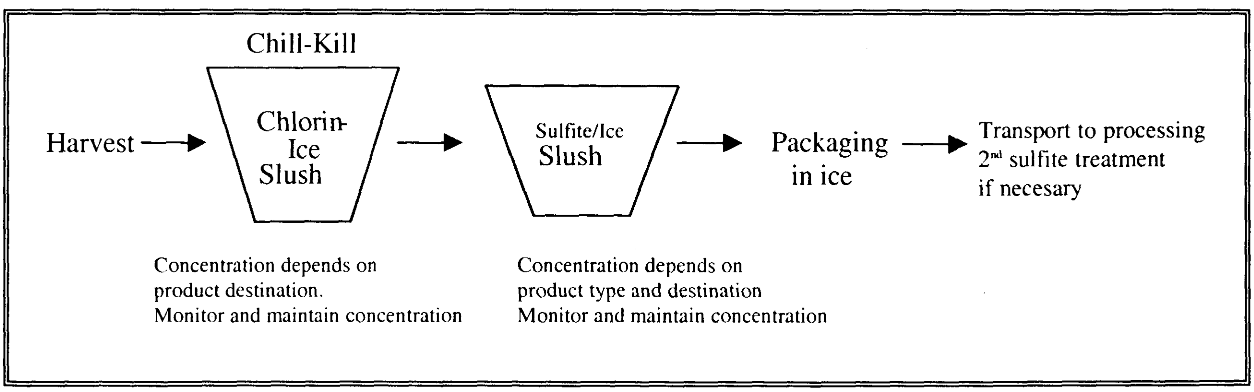
More immediate and extra melanosis treatment is necessary to control black-spot development in the head of the shrimp. The head contains the enzyme and higher oxygen levels that promote rapid development of blackspot.

C. More immediate application of sulfite controls





D. Bacterial and melanosis controls necessary immediately after harvest



Additional Considerations:

Experience with a particular shrimp and farm situation will determine the best combination of dipping times and concentrations to prevent melanosis and reduce bacteria. These treatments are most effective when applied immediately after harvest, even while the shrimp are alive. Often dips are repeated at the processing plant to assure effective treatments. Likewise, there must be a balance between the melanosis and sanitizing treatments. Chlorine and melanosis controls should not be combined in the same treatment. Likewise, draining and rinsing is recommended between treatments with chlorine and melanosis controls. The chlorine will reduce the influence of the melanosis controls. The farmer and processor must learn the best combination of dips to remain effective without leaving excessive sulfite residuals on the shrimp. Excessive treatments can also flavor or discolor the shrimp.

All solutions should be prepared with clean potable water. The solutions should completely cover the entire basket of shrimp. Mild agitation helps mix the solutions around the shrimp.

For some farmed shrimp, the concern for potential pathogenic bacteria calls for an initial antimicrobial treatment with a mild iced chlorine solution. It is believed that this treatment is more effective if the shrimp actively 'drink' the solution to kill any internal bacteria (i.e. treatment should be applied to live shrimp). Following this sanitizing treatment, the shrimp should be washed with clean potable water, before treating for blackspot with sulfites.

To prevent melanosis, shrimp should be immediately washed in a 1.25% bath of sulfite solution (see Melanosis - Sulfites). Treatment time varies depending on whether product has been washed to remove excessive mud and debris prior to dipping and whether the product has been chilled. Although a freshwater pre-rinse could kill some of the shrimp, mud and debris can reduce the effectiveness of the sulfite dip. In general, cleaned shrimp treated with a 1.25% concentration for 1 to 3 minutes have a residual level of 100 ppm. If the product is going to be packaged as head-on, or if the shrimp have not been pre-washed, a higher concentration and a longer exposure time are necessary. In some situations, the farmer or processor may decide to keep the shrimp in an iced sulfite solution or slush for a longer time or during transport to the processing plant. A sulfite solution of 0.25% or less should be used in this situation.

An Everfresh solution can be used if the processor wants to eliminate use of sulfites. Special care is needed when using Everfresh to assure that it is applied before the shrimp begin to die (Appendix 3: Melanosis - Everfresh). Keep in mind that Everfresh cannot be used in chlorinated water.

PRODUCT DEFECTS

What quality problems can result from mishandling at the farm?

Appearance Defects (in alphabetical order):

- **Blackspot or Melanosis:**

Melanosis is a natural chemical reaction that occurs in shrimp and results in a brown, dark green to black discoloration. It is not a safety concern. It is primarily a cosmetic or appearance problem resulting from natural chemical reactions uniquely related to the shell and molting cycle of the shrimp. It begins to occur first on the shell, and if allowed to progress, will taint the surface of the meat. Lots with severe melanosis will be rejected or devalued. Shrimp with blackspot should be removed in the culling step while processing. If melanosis problems persist; the processing plant and farm should evaluate the blackspot control plan.

Preventive Measures: Blackspot can be controlled or prevented by using sodium bisulfite, sodium metabisulfite or Everfresh (4-hexylresorcinol). Reducing exposure to sunlight and immediately icing the products reduces the chance of developing of blackspot (Appendix 3: Melanosis Control).

- **Broken & Damaged:**

Any shrimp that is crushed, mutilated, cut or missing a body segment or tail fins can be considered broken or damaged.

Preventive Measures: Careful handling, use of a proper shrimp to ice ratio, and careful packaging help prevent damage during transport.

• Discoloration due to Heat Abuse:
This condition is caused by excessive exposure to heat. If shrimp are not properly iced after harvest on the farm they will actually begin to cook. The rise in temperature promotes bacterial growth leading to decomposition. Pink discoloration most often occurs along the dorsal edge (top of back), ventral extremities (bottom side and swimmerets) and the tail.

Preventive Measures: Maintaining the shrimp on ice at all times prevents this problem. It is best to harvest at night when there is no sunlight and temperatures are cooler. As a general rule, the total temperature exposure time of the harvest shrimp above 35 °F should be no more than 30 minutes cumulative from time of harvest to icing. THIS GENERAL PRACTICE IS NOT A REGULATORY REQUIREMENT.

RECOMMENDATION
"Less than 30 minute above 35 °F at harvest"

• Loose heads:
This condition occurs when the shrimp head (cephalothorax) have been separated from the body of the shrimp. This problem is due to either enzyme activity or by poor handling of the shrimp. It is a sign of mishandling and temperature abuse of the shrimp.

Preventive Measures: Proper cooling with clean ice and transporting the shrimp in properly packed ice bins can help prevent this problem.

• Milky Shrimp:
Shrimp with white, milky meat appearance is known as 'milky shrimp'. It is caused by a natural microscopic parasite infection. This not a food safety problem, but does degrade the product value.

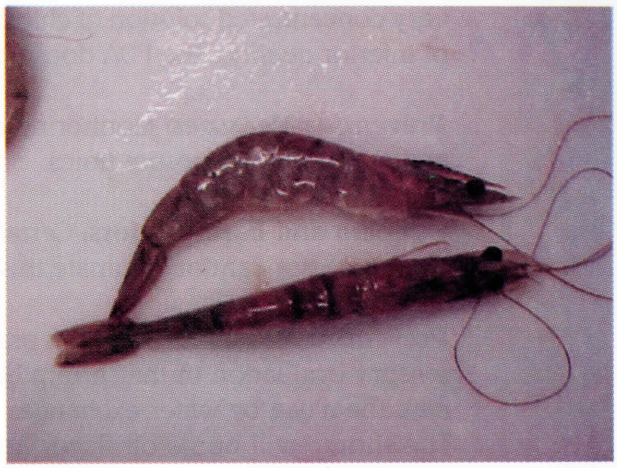
Preventive Measures: Shrimp showing this problem should be rejected during a culling step while processing.

• **Mixed Species:**
Color of the shrimp should be uniform within the package. Mixed colors usually indicate mixed species, some of which may be of inferior quality or type. It could also be the result of shrimp from different ponds or farms.

Preventive Measures: This defect applies only to farms with direct sales since separation of different shrimp types occurs during processing. Appropriate and careful separation of shrimp by species and sources can prevent this problem.

• **Pitted or Gritty Shells:**
In some cases a sandpaper feel on the shrimp shell can be caused when sodium bisulfite or metabisulfite is not dissolved in water before application to shrimp. In excessive amounts, this additive can pit and corrode the shells.

Preventive Measures: Proper application involves dissolving the sodium bisulfite or metabisulfite first in the water before immersing shrimp in the treatment solution. Never simply dust the sodium bisulfite or metabisulfite powder on shrimp or ice used to package the shrimp. A powder application can cause pitting and usually results in an uneven treatment for melanosis.



• **Red Heads:** When shrimp are harvested with feed in the digestive system, a red color develops inside the cephalothorax. Other colors can develop depending on the shrimp diet. This is not a quality or safety issue, but buyers might perceive it as an appearance problem.

Preventive Measures: The problem can be reduced by withholding feed at least 48 hours before the harvest.

• **Soft Shell:**
This is a natural condition that could be considered a defect if product is to be sold shell-on or whole.

Preventive Measures: Farmers should monitor molting cycles and only harvest when 5% or less of the harvest has soft shell.

• **Yellowing:**
This discoloration can be caused by use of excessive amounts of sodium bisulfite. Indications of this are unusual yellowing of the underside of shrimp (swimmerets, tail, etc), as well as, a bleached appearance.

Preventive Measures: Maintaining the appropriate concentration of sodium metabisulfite in the solution and proper product exposure time can prevent this problem.

Odor / Flavor Defects
(in alphabetical order)

• **Odors of Decomposition:**
Objectionable, off-odors are usually due to bacterial spoilage.
Preventive Measures: Proper icing and temperature controls.

• **Chlorine or Chemical smell:** May result when shrimp are washed and sanitized with a very concentrated solution of chlorine. Chlorine may also be used to mask smells in shrimp of inferior quality. The FDA does not accept presence of this smell.

Preventive Measures: Monitoring and maintaining correct amounts of chlorine in water and appropriate exposure times.

• **Choclo and Earthy Odors:** Certain algae blooms within the ponds can cause off-odors. The processor cannot eliminate this unacceptable odor after harvest.

Preventive Measures: Common practice indicates that the best way to deal with these is by sensory evaluation of the shrimp before harvest. If present, the shrimp farmer may eliminate the algae by water exchanges and/or increasing pH of the water with liming agents. The shrimp will purge off flavor and then it will be ready for harvest. The FDA does not accept presence of this smell since it is not characteristic of the shrimp and suggest decomposition.

• **Off flavor in the head:** Objectionable flavor that can result from initial spoilage or previous use of certain feeds. This defect impacts the product when it is intended for head-on commerce. Sensory evaluation needs to be performed on shrimp before harvesting.

• **Petro-Chemical Smell:** Minimal exposure of shrimp to diesel or oil by direct contact or indirectly by fumes can impart a chemical smell to the shrimp.

Preventive Measures: Monitoring of chemicals to prevent potential contamination during harvest will prevent this problem.

Texture Defects
(in alphabetical order)

- **Mushy or Soft Texture Shrimp:**
Occurs when excessive quantities of ice are placed on shrimp resulting in crushing of the product. Soft texture can also result from decomposition.

Preventive measures: Storing shrimp in at least a 1 to 1 weight ratio for shrimp and ice. A 1 to 2 ratios of shrimp to ice is preferred.

APPENDIX 1

CHLORINATION FOR FARM-RAISED SHRIMP

The microbial control and sanitizing benefits from use of chlorine compounds in handling shrimp are obvious and undisputed. The compounds are used during harvest to reduce the natural bacteria coming from the ponds, while additional treatments can be used during final processing. Chlorine is the most widely used sanitizer in seafood processing and possibly the least expensive, yet controls are necessary to prevent excessive use. Elevated concentrations and prolonged exposure times can damage shrimp by discoloration, addition of chemical odors, and causing poor surface texture. Likewise, misuse can contribute to corrosion of equipment and potential adverse by-products.

What types of chlorine compounds are used with shrimp?

There are 3 basic types of chlorine compounds that are used in farming and processing of shrimp and other seafood.

Gaseous chlorine (Cl_2), which comes in bottled cylinders, is most commonly used to treat the water used in the processing plant. Residual levels in the treated processing water can range about 1.0 ppm.

Liquid chlorine (sodium hypochlorite; $NaOCl$), which can be provided in concentrations ranging from 2 to 15%, is often referred to as 'bleach'.

NOTE: Before using a liquid bleach look at the label instructions to make sure this liquid form is approved for food use.

Powdered chlorine (calcium hypochlorite; $Ca(OCl)_2$), which is 100% chlorine, can be dissolved in water to prepare various concentrations. The powdered form is most commonly used on shrimp farms.

CAUTION: The powder should be stored dry until used and should be handled very carefully to prevent hazardous eye contact.

How does chlorine work?

A chlorine solution can contain many effective chemicals with differing microbial killing power. The hypochlorous acid compound (HOCl) provides the most effective kill. All chlorine solutions contain HOCl, but the amount or effective killing power depends on the solution pH and temperature. A pH range of 6 to 7.5 is most effective. If the solution does not have the ability to maintain this effective pH range (buffering), the microbial killing power will be significantly decreased. At pH values less than 5 the solution will become more corrosive, and at lower pH values the solution could release toxic chlorine gas (mustard gas). At pH values greater than 7.5 the solution loses killing power and could be hazardous. For this reason **NEVER** mix chlorine and ammonia since ammonia is basic and raises the pH, thus releasing chlorine gas.

ATTEMPTING TO ADD MORE CHLORINE TO INCREASE THE MICROBIAL KILLING POWER OF A SOLUTION IS NOT EFFECTIVE UNLESS THE SOLUTION PH IS MAINTAINED BETWEEN 6 TO 7.5.

Although warmer solution temperatures can increase the microbial killing power, chlorine solutions work well at cool temperatures and tolerate hard water. Treatments on shrimp farms are usually applied as chilled dips. Careful preparation of the solution concentrations must account for the amount of ice in the solution which will dilute the solution as it melts.

What chlorine concentrations should be used in shrimp farming?

Based on recommendations in the United States, the concentration of chlorine residual that can be applied to foods, including shrimp, is 10 ppm. This recommendation is often confused by interpretation for the residual concentration before food application vs. after the solution is applied to the food. The latter is the correct interpretation. Likewise, there are conflicting recommendations from various countries.

	Recommended Chlorine Concentrations in Solution (ppm)		
	Contacting Food	**Food Contact Surfaces**	**Non-food Contact Surfaces**
Codex	10	100-200	
USA	10	100-200	400
Thailand	2-10		
Canada	7		
Japan	1		
China	0.3		
Finland	0.1		

Source:
ASEAN-Canada Fisheries Post-Harvest Technology Project, 1977.

In contrast, the recommended chlorine concentrations for cleaning food contact surfaces (tables, totes, bins, utensils) and non-food contact surfaces (floors, drains) are higher than for direct food contact.

How can the chlorine solution concentration be measured?

Chlorine concentrations are unstable in solution and will decrease when exposed to organic material like shrimp. The amount of decreased or absorbed chlorine is known as the 'chlorine demand'. The amount of free or remaining chlorine is known as the 'free chlorine', which provides the microbial killing power. This free residual can be simply measured with chlorine test strips. Smell is not a reliable indication of chlorine concentration or killing power. At times, it may be necessary to add more chlorine to maintain the killing power as indicated by the residual measures with the strips.

APPENDIX 2

MELANOSIS CONTROLS - SULFITES

Why it is necessary to use sulfiting agents in shrimp processing?

Sulfite agents, such as sodium bisulfite and sodium metabisulfite, are currently used to prevent melanosis or 'blackspotting' on certain shrimp, lobsters and other crustaceans. These compounds prevent the chemical reactions caused by enzymes known as polyphenoloxidases (PPO), which are involved with the natural shellfish shedding process. After harvest and death, the PPO systems are still active and can promote the development of black pigments (melanin) about the shell and on the surface of the meat. Proper icing or freezing reduces the PPO activity, but the enzyme activity slowly continues at refrigeration temperatures and is accelerated in thawed product. The melanin or black discoloration is not a toxic or disease causing substance, but it is commonly interpreted as a sign for poor product quality and mishandling. Properly applied immediately after harvest, the sulfiting agents can reduce the PPO enzyme activity and provide some partial bleaching to help maintain the preferred shrimp appearance.

What concentration of sulfite agents should I use?

Previous experience dating back to the 1950's determined the recommended method for uniform and effective control of Penaeid shrimp melanosis was a 1 minute dip in a 1.25% sulfite solution, followed by rinsing, draining and storage in ice, refrigeration or as frozen. A higher concentration is no more effective in reducing melanosis, but it is more expensive and could cause quality problems such as pitted or sandpaper texture shells, and yellow discoloration.

What is the best application method for sulfites?

Sulfiting agents used to prevent shrimp melanosis are best applied immediately after harvest. The most effective treatment is to place the shrimp to be treated in a basket. Then immerse this basket in the 1.25% sulfite dip solution for 1 to 3 minutes. After treatment, shrimp are drained and then stored on ice for transport to processing plant. Unreliable and/or ineffective ways to use sulfites include sprinkling the powder on the last top layer of ice or on each layer of shrimp. Also, it is not recommended to apply the sulfite treatments through applications in or on the ice used to cool the shrimp. These methods do not provide a uniform effective treatment, and possible overuse can result in a tougher meat texture and product weight loss.

In some situations, the farmer or processor may decide to keep the shrimp in a iced sulfite solution or slush for longer time or during transport to the processing plant. A 0.25% sulfites or less concentrated solution or should be used in this situation.

How do I prepare a sulfite solution?

Sulfite solutions are prepared by dissolving either sodium bisulfite or sodium metabisulfite in water. The following table shows quantities to use to prepare a 1.25% solution.

1.25% Sulfite Mixtures	
Clean Water	**Sulfiting Agent**
1 Liter	12.5 g
1 Gallon	47.3 g or 0.1 Lb
10 Gallons (85 lbs*)	1 Lb or 1.5 cups*
30 Gallons (250 Lbs)	3.1 Lbs or 4 1/2 cups*
60 Gallons (500 Lbs)	6.2 Lbs or 9 cups*

* 1 cup equals 8 fluid ounces, sulfiting agents come as powders

CAUTION !

Sulfite power can release toxic sulfur dioxide fumes when in contact with moisture or water. Store sulfite powers in sealed, water tight container placed in well-ventilated areas. Prepare sulfite solutions in well-ventilated or open areas. A 1.25% solution is not dangerous, but can irritate eyes and breathing if closely inhaled.

How many times can I use this solution?

Sulfite dips gradually lose their sulfite concentration or strength with use. It is recommended that dips be checked at regular intervals with test paper. These will change color according to the concentration of sulfites in the dip. Weak solutions should be discarded. Experience with a particular shrimp, shrimp sizes, and different farm conditions will indicate the best use rates. A general rule is treat 50 pounds of shrimp per 10 gallons of fresh solution.

What does ice storage, thawing and cooking affect the sulfite residual on shrimp?

Prolonged icing, washes and thawing can partially reduce the residual amount of sulfite on treated shrimp. If prolonged storage of shrimp in ice or ice slush is necessary, an additional mild treatment may be applied at the processing plant. Experience will indicate the need for additional treatments. Thawing, peeling and washing can reduce residual levels on adulterated shrimp, butthe amount of residual reduction is limited. Most typical cooking methods offer little advantage in reducing sulfite levels on shrimp.

How are sulfite agents regulated in shrimp?

There is no regulatory limit specified in the United States for the amount of sulfite residual that can be on shrimp, but it is implied that residuals less than 100 ppm are adequate to achieve the intended effect to prevent melanosis. Other countries have specified limits ranging from 60 to 100 ppm for raw shrimp, and as low as 30 ppm for cooked shrimp. These limits are not based on measures for product safety. The hazardous level for sulfite residuals is unknown and varies for different consumer sensitivities.

Why it is important to label sulfites in the product ingredient list?

Regulations have specified sulfite residual limits for many foods and prohibited use on fresh fruits and vegetables as sold or served raw. These controls are necessary to prevent adverse health effects for certain consumers, particularly hypersensitive asthmatic persons which could have severe respiratory and allergic type reactions that could be life threatening. Adverse health reactions are rare for sulfite treated shrimp, lobster and other crustaceans, yet continuing United States regulatory and consumer concerns advocate controls for sulfite use. Improper labeling is subject to regulatory seizure and penalties. Labeling declarations indicating that the product was previously treated are required if the sulfite residual level on the raw or cooked shrimp is above 10 ppm.

It is necessary to monitor for sulfite residuals?

Usually, the processor or retail firm does not directly control sulfite applications. To assure product safety and regulatory compliance, these buyers need useful monitoring procedures. In most instances, monitoring of sulfite residuals should be an integral part of a firm's HACCP (Hazard Analysis Critical Control) program. HACCP monitoring procedures need to be rapid and convenient to suit daily on-site use, but the analytical procedures are complicated because of the sulfite residuals can be tightly bound to the edible muscle tissue.

How do I monitor for sulfite residuals in the edible portion of the shrimp?

Analytical procedures must measure the sulfite residual as it exits in the edible muscle. Simple test paper and test drops are recommended for routine screening during processing and buying. More accurate methods require a proper laboratory setting and trained personnel. The involved lab methods are not recommended for routine commercial settings, yet it offers a final contractual or third party option for analytical verification.

What screening procedures are available to monitor for sulfites?

Test Drops

Procedure - Direct application of one drop of an activator solution and one drop of test reagent to the product surface ('Alert' method available from Neogen Corp.).

Interpretation - Blue to violet color reactions indicate the presence of sulfites. A light violet hue or complete disappearance of color within one minute suggests excessive sulfite use. WARNING: There may be slight color variations observed for various shrimp species and other crustaceans. The utility of the test kit should be evaluated with the particular products in question. In other words, a firm should confirm possible color reactions with product that has no prior handling with any sulfite agents.

Limitations - This test is used to indicate presence or prior use of sulfiting agents to treat shrimp. The test cannot be accurately used to measure ppm sulfite residual levels on the shrimp.

Test Papers

Procedure- Shrimp shell surface or between the shell and meat is touched for 30 seconds with a strip of sulfite paper. The sulfite present in the shrimp will produce a color change in the test paper.

Interpretation- The paper turns to a specific color depending on the concentration of sulfite present. Quantification of the strip color change is determined by comparison with a color chart provided on the container label.

Limitations- The test was developed for liquids, and so test may produce many false positives (i.e. suggesting sulfites are present when they are not). The test cannot be accurately used to measure ppm sulfite residual levels on the shrimp.

Malachite Green Test

Procedure - This method is less accurate than the test drops. A certain amount of formulated green dye is applied to a certain amount of fine chopped or blended sample of edible shrimp or lobster meat.

Interpretation - Excessive sulfite residuals will bleach out the green color depending on the amount of dye and shrimp sample pre-measured to correspond to a certain sulfite level (i.e., 100 ppm or less). This method is useful to indicate presence of sulfites if the dye is measured to bleach at approximately 50 ppm. Most effective sulfite treatments for shrimp leave a residual near or above 50 ppm.

Limitations - Interpretation requires experience with known standards and use of pictures for reference. Results only indicate compliance or excessive residuals about one set sulfite concentration.

What methods are available for verification of sulfite residuals?

Monier-Williams Test (Official Method)

Procedure - Prolonged acid and heat extraction utilizing special glassware and toxic chemicals, followed by tedious titration.

Interpretation - Represents the current official procedure recognized by regulatory authorities for determination of the actual sulfite residual concentration (i.e., ppm's).

Limitations - The results are subject to variation due to differences in product types and technical experience. The analytical detection limited for sulfite residuals is approximately 10 ppm which serves as the legal limit for required labeling of treated shrimp products.

Rapid Distillation and Redox Titration

Procedure - Acid distillation using specialized equipment followed by an iodine titration for an end-point color change.

Interpretation - Samples are steam distilled while the condensate is titrated with iodine. It is necessary to compare the color of the solution at the end-point to that of standards prepared at the beginning of the titration.

Limitation - Slight variations may occur due to subjective end-point determinations.

Volumetric Iodine Titration

Procedure: Alkali extraction followed by an iodine titration for an end-point color change Two shrimp samples are exposed to alkali solution. After being neutralized, hydrogen peroxide is added to one sample, and both are titrated with iodide solution.

Interpretation: The measured difference between samples is reported as the concentration of sulfite residual. The test is comparatively convenient, but it requires experience to judge the end point for titrations.

Limitation: Slight variations may occur due to subjective end-point determinations.

APPENDIX 3

MELANOSIS CONTROL - EVERFRESH

What is EverFresh?

Everfresh is a common name for a special chemical (4-hexylresorcinol) that binds the enzyme that causes melanosis. After dipping in an Everfresh solution, melanosis will not occur after rinsing, refrigerating, freezing or thawing. It works best if applied when the shrimp are alive.

How can I use Everfresh at the farm?

EverFresh is used in dips just like sulfites. One pouch of EverFresh treats 250 kilograms (550 Lbs) of shrimp. Each pouch is dissolved in 25 gallons (95 liters) of available clean fresh water, brackish water or seawater. The only requirement is that it is non-chlorinated.

How long does it take to treat with EverFresh?

Shrimp are placed in a basket for a 2-minute dip with agitating up and down to make sure all surfaces come into contact with the EverFresh solution.

How do I prepare an Everfresh Solution?

Water	Pouches of Everfresh (200 g)	Recommend Amount of Shrimp (lbs) that can be treated before change solution
25 gallons (210 lbs)	1	500 to 600
50 gallons (420 lbs)	2	1000 to 1200
75 gallons (625 lbs)	3	1500 to 1800

What other things must be considered when using EverFresh?

- Treat shrimp before exposing the shrimp to chlorine solutions or concen trated brines.
- Avoid use of highly concentrated chlorinated water.
- Water temperature should be between 2 °C ands 27 °C. Everfresh works better at ambient temperature.
- Never sprinkle Everfresh directly onto seafood.
- Using more Everfresh or extending the time shrimp is submerged will not increase the effectiveness of EverFresh.

APPENDIX 4

Records and Control Sheets

Therapeutic Agents Application Record

Farm Name:______________________ Location:________________________

Pond Number	Shrimp Illness	Therapeutic Agent Used	Application Method	Dosage	Withdrawal Time (Days)	First Application date / time	Last application date / time	Applicator	Harvest Date

Feed / Weight Control Record

Pond Number:________________________ Stocking Date:__________________

Harvest Date:________________________

Farm Name:__________________________ Farm Location:__________________

Feed type						
Day	**Month**	**Month**	**Month**	**Month**	**Month**	**Month**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
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19						
20						
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22						
23						
24						
25						
26						
27						
28						
29						
30						
31						

Pre-Harvest Product Evaluation Record

Pond #_______________________

	First Evaluation ***Date*** ________			***Second Evaluation (if needed)*** ***Date*** ________			***Third Evaluation (if needed)*** ***Date*** ________		
Parameter	**✓/X**	**Corrective Action(s)**	***Ready to Harvest (Yes/No)***	**✓/X**	**Corrective Action(s)**	***Ready to Harvest (Yes/No)***	**✓/X**	**Corrective Action(s)**	***Ready to Harvest (Yes/No)***
Shell Condition & Texture									
Flavor of the Head (Off-flavors)									
Flavor of the Body (Off-flavors)									
Salmonella in the Shrimp (Presence or Absence)									
Medicinals Application Control Check									

✓ =Acceptable X=Unacceptable

APPENDIX 5

U.S. REGULATORY TOLERANCES, METHODS AND AUTHORITES

Tolerancias

PESTICIDES		
Deleterious Substance	**Level**	**Food Commodity**
Aldrin/Dieldrin[a]	0.3 ppm	All fish
Benzene hexachloride	0.3 ppm	Frog legs
Chlordane	0.3 ppm	All fish
Chlordecone[b]	0.3 ppm	All fish
	0.4 ppm	Crabmeat
DDT, TDE, DDE[c]	5.0 ppm	All fish
Diquat[d]	0.1 ppm	All fish
Fluridone[d]	0.5 ppm	Fin fish and crayfish
Glyphosate[d]	0.25ppm	Fin fish
	3.0 ppm	Shellfish
Heptachlor / Heptachlor Epoxide[e]	0.3 ppm	All fish
Mirex	0.1 ppm	All fish
Polychlorinated Biphenyls (PCB's)[d]	2.0 ppm	All fish
Simazine[d]	12.0 ppm	Finfish
2,4-D[d]	1.0 ppm	All fish

Source: WWW.FDA.GOV , FDA's Fish & Fisheries Products Hazards & Control Guide: Second Edition 1998

TOXIC ELEMENTS		
Toxic elements	**Level**	**Food Commodity**
Arsenic (total)	76 ppm	Crustacea
	86 ppm	Molluscan bivalves
Cadmium	3 ppm	Crustacea
	4 ppm	Molluscan bivalves
Chromium	12 ppm	Crustacea
	13 ppm	Molluscan bivalves
Lead	1.5 ppm	Crustacea
	1.7 ppm	Molluscan bivalves
Nickel	70 ppm	Crustacea
	80 ppm	Molluscan bivalves
Methyl Mercury	1 ppm	All fish[b]

Source: WWW.FDA.GOV , FDA's Fish & Fisheries Products Hazards & Control Guide: Second Edition 1998

a The action level for aldrin and dieldrin are for residues of the pesticides individually or in combination. However, in adding amounts of aldrin and dieldrin, do not count aldrin or dieldrin found at below 0.1 ppm.
b Previously listed as Kepone, the trade name of chlordecone.
c The action level for DDT, TDE, and DDE are for residues of the pesticides individually or in combination. However, in adding amounts of DDT, TDE, and DDE, do not count any of the three found below 0.2 ppm.
d The levels published in 21 CFR & 40 CFR represent tolerances, rather than guidance levels or action levels.
e The action level for heptachlor and heptachlor epoxide is for the pesticides individually or in combination. However, in adding amounts of heptachlor and heptachlor epoxide, do not count heptachlor or heptachlor epoxide found below 0.1 ppm.
Note: the term "fish" refers to fresh or saltwater finfish, crustaceans, other forms of aquatic animal life other than birds or mammals, and all mollusks, as defined in 21 CFR 123.3(d).

APPENDIX 6

Analytical Methodology for Chemical Contaminants and Therapeutic Agents

Lead

Lead in fish: Atomic absorption spectrophotometric method (AOAC, 1995d).
Lead in fish: Polarographic method (AOAC, 1995e).

Mercury

Mercury (methyl) in fish and shellfish: Gas chromatographic method (AOAC, 1995f).
Mercury (Methyl) in fish and shellfish: Rapid gas chromatographic method (AOAC, 1995g).
Mercury (methyl) in seafood: Liquid chromatographic - atomic absorption. spectrophotometric method (AOAC, 1995h).

Pesticides

Organochlorine and organophosphorous pesticide residues: General multiresidue method (AOAC, 1995a).
Organochlorine and organophosphorous pesticide residues: Gas chromatographic method (AOAC, 1995b).
Organochlorine pesticide and polychlorinated biphenyl residues in fish - Gas chromatographic method (AOAC, 1995c).

Therapeutic agents

Oxitetracyclin in Feeds: (AOAC, 1995 Chapter 5, p.47).
Oxitetracyclin in Animal Tissue: (AOAC, 1995 Chapter 23, p.19).
Furanzolidone in Feed and Premixes: (AOAC, 1995 Chapter 5, p.11-13).
Chloramphenicol in milk: (AOAC, 1995 Chapter 33, p. 42-43).
Formaldehyde in Food: AOAC, 1995 Chapter 47, p. 16).

APPENDIX 7

Food and Environmental Regulatory Agencies in the United States of America

(**Source**: publication B-5085 - Guide to Drug, Vaccine, and pesticide Use in Aquaculture)

a. **United States Food and Drug Administration (FDA)** - www.fda.gov: responsible for the safety, wholesomeness, and proper labeling of food products; responsible for assuring compliance with current seafood regulations, including HACCP.

b. **Center for Veterinary Medicine (CVM)** - www.usda.gov: responsible for the regu lation of the manufacturing, distribution and proper use of animal drugs.

c. **Center for Food Science and Applied Nutrition (CFSAN)** - www.cfsan.fda.gov: responsible for conducting research and develop standards for the composition, quality, nutrition, labeling and safety of foods, food additives and color additives.

d. **U.S. Environmental Protection Agency (EPA)** - www.epa.gov: responsible for registering and licensing all pesticides used in the United States. Also, sets toler ances and maximum limits for pesticide residues in foods and animal feed.

e. **Animal and Plant Health Inspection Services (APHIS-USDA)** - www.usda.gov: regulates veterinary biologics produced in, shipped into, or exported from the US, including vaccines, therapeutants and diagnosis test kits.

State Regulatory Agencies regulate all food processed or marketed for human consumption in each individual State.

APPENDIX 8

SOURCES FOR ADDITIONAL INFORMATION

Seafood HACCP, Safety, and Quality Topics on the Internet: Selected Site List with Brief Descriptions

21 USC Chapter 9 - Federal Food, Drug and Cosmetic Act
http://www.law.cornell.edu/uscode/21/ch9.html
Access to the US Code Title 21 - Foods and Drugs, with a direct link to the Federal Food, Drug, and Cosmetic Act.

AFSIC Aquaculture Resources - NAL USDA
http://www.nal.usda.gov/afsic/afsaqua.htm
Includes a very large database of aquaculture-related web sites and links.

Aquaculture Network Information Center (AquaNIC) Home Page
http://ag.ansc.purdue.edu/aquanic/
Good source of aquaculture newsletters and more aquaculture-related links.

ASEAN Fisheries Post-Harvest Information Network
http://www.asean.fishnet.gov.sg/p19.html
A diverse site from Southeast Asia which includes online publications (i.e., Hazard Control for Aquacultured Shrimp) and the Marine Fisheries Research Department Online Library Search.

Codex Alimentarius Commission
http://www.fao.org/waicent/faoinfo/economic/esn/CODEX/Default.htm
General site covering Codex Alimentarius activities including committee reports and meetings.

Codex Alimentarius - Basic Texts on Food Hygiene
http://www.fao.org/waicent/faoinfo/economic/esn/CODEX/STANDARD/fh_basic.pdf
Downloadable Texts which include General Principles of Food Hygiene and HACCP.

CSIRO Australia
http://www.csiro.au/
General information site of the Commonwealth Scientific and Industrial Research Organization of Australia. Food Processing and Meat, Dairy, and Aquaculture Divisions are relevant.

CSIRO Aquaculture Introduction
http://www.marine.csiro.au/aquaculture/intro.html
Further information from CSIRO concerning aquaculture and marine research. This web site can be slow and difficult to connect to.

Europa - European Union Policy
http://europa.eu.int/
European Union Policy site addressing production and marketing of fish and fishery products, as well as meat, eggs, etc.

Food and Drug Administration Home Page
http://www.fda.gov/
Gateway into the FDA web site.

FDA - Center for Food Safety & Applied Nutrition - Seafood
http://vm.cfsan.fda.gov/seafood1.html
Excellent source of seafood HACCP and Safety information. Site includes the Seafood HACCP Final Rule, the Fish and Fishery Products Hazards and Controls Guide, Seafood HACCP Question and Answer, and great links to further sites.

FDA - Office of Regulatory Affairs
http://www.fda.gov/ora/ora_home_page.html
A direct link to FDA Compliance Policy Guides and Regulatory Procedures Manual, this site also includes Inspectional References, Science References, and the Import Program.

Harbor Branch Oceanographic Institution, Inc.
http://www.hboi.edu/
This site has sections directed toward teaching and research in the areas of aquaculture of fish, shellfish, and crustaceans. Culture methods and systems are emphasized.

InfoFish
http://www.jaring.my/infofish/
A good web site that is published by an intergovernmental organization that provides marketing and technical information to the Asian-Pacific seafood industry. The most useful links are The Fish Inspector and InfoFish International.

Infopesca - Spanish
http://tips.org.uy/infopesca/
Similar to InfoFish site but developed for the Latin American and Caribbean region.

National Food Safety Database USDA-FDA Foodborne...Database
http://www.foodsafety.org/dbseai.htm
Food safety information for a wide variety of food products, including seafood, in a searchable format.

NOAA Fisheries - National Marine Fisheries Service
http://www.nmfs.gov/
This web site has links to a wide variety of fisheries issues. The Seafood Inspection Division is of particular interest with sections related to HACCP and Sensory Training, Publications (HACCP and Sanitation), and International Activities. There is also a link to a very useful NMFS Fisheries Statistics Page.

SeafoodNIC Home Page
http://www-seafood.ucdavis.edu/
The Seafood Network Information Center web site in an excellent overall web site with very useful links to the Seafood HACCP Alliance, UC Davis Seafood Information, and the IFT Seafood Technology Division. The Seafood HACCP Alliance section has links to Guidelines and Regulations and the Compendium of Fish and Fishery Products Processes, Hazards and Controls. There are also good links to other information sources.

Seafood NIC Home Page - HACCP Plans
http://www-seafood.ucdavis.edu/haccp/Plans.htm
This site is a direct link to UC Davis Seafood Information Generic HACCP Plans.

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9

SHRIMP FARM BUSINESS MANAGEMENT AND ECONOMICS

SHRIMP FARM BUSINESS MANAGEMENT AND ECONOMICS

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Introduction

Best Management Practices (BMPs) are designed to improve farming efficiency and reduce risk while minimizing or eliminating potential environmental impacts. It is not surprising that implementation of BMPs should yield multiple benefits. The underlying premise of BMPs is that making better use of resources and inputs will have positive effects on redu-cing waste while improving various aspects of production such as volume, quality, health and food conversion ratio, among others. Use of BMPs entails careful planning and oversight, helping to reduce risks.

Development of BMPs for shrimp farming is a relatively new endeavor for the industry. Industry groups, researchers and environmental managers have focused intensively on the topic during the 1990's with the result that several fairly similar sets of BMPs have now been developed. As the shrimp industry moves from developing to implementing BMPs, economic analysis coupled with environmental monitoring will be required to determine if BMPs produce the intended effects and where areas for improvement lie. Increased understanding and refinement of BMPs will make a better case for industry-wide adoption.

Two levels of capability are addressed in this chapter.

First, this work is intended to provide information on basic business management tools for shrimp farmers. A shrimp farmer who masters these simple tools will be better able to manage the production and financial aspects of any operation. Additionally, as new practices are adopted, these tools provide a means to quantitatively determine whether the results benefit the business. Armed with the tools presented in this chapter, a shrimp farmer will be able to collect the information needed to manage a business, conduct simple analyses to determine how management practices affect the financial operation and then identify how specific practices can be fine tuned to increase benefits.

Secondly, beyond the basic business management tools, introductory information is provided on the use of linear programming as tool for determining the best use of scarce resources in a variety of management schemes. The concept of risk analysis or level of uncertainty associated with farming practices is also described. Both provide valuable decision-making information for a shrimp farmer, but their utility has previously been limited by the complexity of making the required calculations. Thanks to new software which allows a user to easily learn and use these methods, more sophisticated analysis yielding more useful information can now be conducted by shrimp farmers after a minimum of training.

For those interested in progressing beyond the basic use of standard business management tools, an accompanying training manual, "Tools for Better Management Decision Making for Shrimp Farmers" (Engle and Valderrama 2001) is recommended and is available from the Central American University Press, Managua, Nicaragua.

Shrimp farm business management

Efficient management of a shrimp farm can make the difference between profits and losses even in years with unfavorable prices and costs. Farm management involves more than just taking care of the biological processes involved; it includes paying close attention to economic and financial measures of the farm business also. This chapter will provide a practical overview of economic and financial indicators and analyses to use to better understand the performance of the shrimp farm business. This should assist farm owners and managers to make more informed management decisions on shrimp farms.

The examples used in this chapter are all based on data obtained from a survey of shrimp farmers in Honduras in 1997. The sample budgets and analyses are based on prices and cost conditions in the country at that time as identified in the survey.

Enterprise profitability

The purpose of a business is to make money, or to generate profits. This would seem to be a simple and straightforward concept. Nevertheless, there are several different ways to look at the profitability of a business activity. The particular type of analysis to be done will vary with the time frame selected, the scope or scale of the activity being selected, and the availability of data to do the analysis.

This chapter will first present an analysis of the profitability of shrimp farming under the assumption that this is a new activity for the individual. The individual is not currently in the shrimp business. The first step for this individual would be to look at whether or not shrimp farming is profitable in a general sense in a *typical* or *representative* year. For this analysis, the individual would use *enterprise budget analysis* to see whether shrimp farming was profitable or not. Profits would be determined by whether or not revenues generated from sale of shrimp were greater than the sum of all costs involved in shrimp production. *Average* or *typical* values would be used for all costs and prices in the analysis.

Next, we will move on to analyze in a general way whether or not it would be profitable to make a relatively small change in the management of the farm. This change might be an expansion of existing acreage by building more ponds, adding a post-larval acclimation unit or using more aeration and less water exchange. The proposed, small change would be analyzed with a *partial budget*. In this case, all the new costs, added benefits, reduced costs, or reduced benefits that would result from the change would be included to see whether or not, overall, the benefits exceed the costs.

For a farm that is already in business, the best way to measure profit is to evaluate it on an annual basis using an income statement. The *income statement* is similar to an enterprise budget except that it uses real farm revenues and expenses rather than average or typical prices and costs. If the total farm revenues from sales generated for the period are greater than the costs, then profits were generated for that period.

Many individuals plan over a broader horizon than one individual year and want to know how profitable is the *investment of their capital over time*. For this analysis, an indicator known as the *internal rate of return* is used. It shows the returns to the capital investment over the life of the investment. These returns measure profitability of the use of the investment capital.

Finally, this chapter contains a section on economic optimization of shrimp farming. Specifically, the process of income-maximization in a shrimp farm is illustrated through the use of a mathematical technique known as Linear Programming and a spreadsheet-based computer program (Solver©). The incorporation and assessment of risk levels in enterprise budgets will also be demonstrated through the use of a risk analysis computer program (Crystal Ball©).

Enterprise Budget Analysis-is it possible to make money from this activity?

The first step in the analysis of the economics of shrimp farming is to determine if it is possible to make money generally from this type of business activity. For this, an analysis is done called an enterprise budget analysis. An enterprise budget provides a generalized snap-shot of the costs and returns of a particular enterprise, in this case shrimp production, for a particular period of time. Figure 1 presents an example of a shrimp farm budget developed with data from Honduras.

It is important to think about the time period and the budgetary unit carefully. In aquaculture, a common budgetary unit is one pond of an average size for the type of business being analyzed. The example in Figure 1 is a whole-farm budget for a 350-ha shrimp farm in Honduras. Time periods used to develop enterprise budgets can be based on one production cycle, but are most often developed for a one-year period as is the case in Figure 1.

The basic headings of an enterprise budget can be seen in Figure 1a. The first column lists the various items to be included. The second column lists a description of each item. It is important that each item be thoroughly described. For example, *gross returns* (income generated from the sale of shrimp) on most shrimp farms in Central America will come from sales of more than one size of shrimp. Since shrimp price varies with the size of the shrimp, these line items must be separated and described succinctly in the budget. Costs are divided into *variable* (those that vary with production; also called operating costs) and *fixed* (costs that will be incurred regardless of the level of production; also called ownership costs). Under variable costs, it is important to specify whether post-larvae are wild-caught or hatchery-raised because prices and production performance will be different. Feed descriptions should specify the percent protein and the fertilizer description should specify the type and formulation of fertilizer. The description of each item should provide sufficient information so as to be able to identify prices and quantities needed. Fixed costs typically require additional supporting tables to identify *depreciation costs* and *interest levels.*

The next column indicates the unit used. Units must be specified carefully and are usually selected based on the most common unit purchased. It is critical that the units and the prices and quantities across rows all are consistent. In the Gross Returns row, in the budget in Figure 1a, the unit used is the pound. This is the unit of sale of shrimp in Honduras. Post-larvae are sold in units of 1,000 each and this is the unit used in the budget. Feed and fertilizer are sold by the hundredweight and fuel by the gallon. The unit used for labor is an annual salary. In some budgets, an hourly wage rate is used if workers are paid by the hour. Total variable costs and the fixed cost items are specified as a total amount of dollars. Since fixed costs frequently are detailed in other tables and statements, a simple total is listed on the budget itself.

Quantities are expressed in the next column as the total quantity needed for one year of production for the production unit specified in the enterprise budget. Since the example budget is for a 350-ha shrimp farm, all the quantities needed for a 350-ha shrimp farm for one year are listed. In this case, the basic production assumptions are listed in Figure 1b. In this example, dry-season yields are 963 lb/ha of shrimp tails, multiplied by the 350 ha gives a quantity of 337,198 lb/ha of 71-90 shrimp tails. In the wet season, a yield of 1,922 lb/ha multiplied times 350 ha gives a quantity of 672,591 lb of 41-50 shrimp. The quantity specified for each cost item likewise is for the budget unit of the farm and corresponds to the unit specified. The quantity of the interest on operating capital in this example was determined by assuming that 75% of total variable costs (exclusive of marketing costs) would need to be covered though operating, short-term loans.

The next column in the budget is for prices and unit costs. Shrimp are sold for an average of $3.25 for 71-90 count shrimp and $4.05/lb for 41-50 count shrimp/lb. These prices appear in the column under price. It is important to use average prices in an enterprise budget. All other prices listed are average expected prices for the unit listed. The interest rate used in this budget for interest on operating capital is 36%.

The next column is the total cost or total revenue. This value is obtained by multiplying the quantity by the price/unit. For example, the price of $3.25/lb of 71-90 count shrimp is multiplied by the quantity of 337,198 lb to get total revenue of $1,095,894. Under variable costs, the price of $23.08 for a hundredweight of 25% protein feed is multiplied by the 24,859 hundredweights of feed required for this 350-ha shrimp farm for one entire year of production.

In this same column, once all the costs have been calculated, they are summed to obtain the *Total Variable Costs.* Subtracting Total Variable Costs from the Gross Returns gives a measure of the *Returns above Variable Costs.* The positive Returns Above Variable Costs indicates that it is profitable to operate in the short run. All variable costs of production are covered. However, if Returns Above Variable Costs were negative, it would be best to minimize losses by shutting down all production activities.

In the next section of the enterprise budget, fixed costs are specified. Fixed costs include depreciation, interest on the investment, taxes and insurance, and any other costs that are not related to the actual production of the business. These costs are summed to obtain *Total Fixed* Costs. These are added to Total Variable Costs to obtain *Total Costs.* Subtracting Total Costs from Gross Returns, generates *Net Returns.* Net returns are the actual measure of pro-fit for this business. In this case, net returns are positive at $467,206. This level of net returns indicates that this type of enterprise, given the prices and costs used in this budget, is pro-fitable, even in the longer term. If net returns were negative, then it would not be profitable.

Breakeven Analysis-how much, and at what price, must be produced to be profitable?

Breakeven prices and yields offer additional insights into the overall feasibility of the operation. *Breakeven price above variable cost* is calculated by dividing total variable costs by the total quantity produced in the farm. In this budget, breakeven price above total variable cost was $3.03/lb of shrimp produced. This indicates that shrimp production will be profitable as long as price is above $3.03/lb.

Breakeven price above total cost is calculated by dividing total costs by the quantity produced in the 350 ha of the farm. In these budgets, this breakeven price comes out to $3.32/lb. In other words, as long as the price of shrimp is above $3.32/lb, this operation is profitable in the long term; all annual variable and fixed costs will be covered at this price.

Breakeven yield is calculated in a similar manner. Breakeven yield above variable cost is calculated by dividing total variable costs by the price and then by the 350 ha in the farm to obtain 2,311 lb/ha. As long as production per ha is above 2,311 lb, then it is profitable to raise shrimp in the short run. Breakeven yield above total costs is calculated by dividing total costs by the price and then dividing by the 350 ha in the farm to obtain a breakeven yield of 2,534 lb/ha. If production levels are above 2,534 lb/ha, this operation will be profitable, even in the long run. At this level of production, there is enough production to be able to cover all variable and all fixed costs.

Sensitivity Analysis-what effect do varying prices and costs have on profitability?

Enterprise budgets should always be developed based on average expected prices, costs, quantities, and yields. If 10 year averages are available, these can be used, but it is important to use conservative estimates. In some cases, certain prices and costs may be highly variable. In these cases, especially when the particular price or quantity has a large effect on net returns, a type of analysis called a sensitivity analysis can be done. In a *sensitivity analysis*, a range of possible values for the particular price or quantity in question is substituted for the mean value and a table developed.

Figures 2a and 2b provide examples of sensitivity analyses done for the shrimp budgets by varying feed prices and survival. As an example, as feed prices increased from $15.38/hundredweight to $30.77/hundredweight, net returns/ha decreased from $2,029 to $641/ha. Breakeven prices increased from $3.08 to $3.56/lb. In Figure 2b, as survival increased from 20% to 80%, net returns/ha increased from -$2,718/ha to $4,508/ha and breakeven prices above total costs decreased from $5.71 to $2.77/lb.

Partial Budget Analysis-will small management changes have an effect?

A **partial budget** is developed when the farm manager is considering a relatively small change on the farm. This change may involve building additional ponds, adding additional aerators to replace water exchange, changing stocking rates, etc.

To develop a partial budget analysis, it is necessary to define a base production scenario in sufficient detail to identify the changes that would result. The following categories are used in the partial budget: Additional Revenue, Additional Costs, Reduced Revenue, and Reduced Costs.

Additional revenue is revenue to be received only if this alternative is adopted. It is not received under the base production scenario. Additional revenue can be received if a new enterprise is added or if there is a change that will cause yields, production levels, or selling price to increase.

Reduced costs are those incurred under the base production scenario that would no longer exist under the treatment being analyzed. Cost reduction can be due to eliminating an enterprise, reducing input use, substituting more of one input for another, or being able to purchase inputs at a lower price. Reduced costs may be either fixed or variable. A reduction in fixed costs will occur if the proposed treatment will reduce or eliminate the current investment in machinery, equipment, breeding livestock, land, or buildings.

Additional costs are costs that do not exist in the base production scenario. The treatment being analyzed may cause additional costs because of the use of new production inputs or the expanded use of production inputs. Another cause would be substituting more of one input for another. Additional costs may be either variable or fixed as there will be additional fixed costs whenever the proposed alternative requires additional capital investment.

Reduced revenue is revenue received under the base production scenario that is not received in the treatment being analyzed. Revenue may be reduced if the change causes a reduction in yields or production levels, or if the selling price will decrease.

Once the data are compiled for each treatment in the partial budget format sketched out below, the total value is computed within each category, i.e., all the additional costs are summed to obtain *total additional costs.* The value of the additional costs is added to the reduced revenue. This represents the negative or adverse effect on profits for this particular treatment. On the other side, the total value of the additional revenues is added to the reduced costs to compute the total value of the benefits of this particular treatment. The sum of the additional costs and reduced revenue is subtracted from the sum of the additional revenue and reduced costs to calculate the net change if this treatment were adopted. If the net change is negative, then the base production scenario is more profitable. However, if the net change is positive, then this treatment is more profitable than the base scenario. That treatment that has the highest positive net change is the most profitable alternative of those analyzed.

Figure 3 presents an analysis of a proposed change on a shrimp farm of switching to new, more expensive types of hatchery post-larvae. The advantage of these post-larvae is that they exhibit higher survival rates.

In the partial budget format, then, there would be additional shrimp revenue with a value of $1,905,123. Figure 3 also provides details of the additional costs that would be incurred by switching to a different post-larvae type. There would be no reduced costs nor reduced revenue involved in making this type of change in the farm operation. The net change in profit would be $751,534. Since the net change is positive, the proposed change is profitable. If the net change had been negative, then it would not be profitable to make this change.

Monitoring Business Performance

Monitoring profits

A financial statement referred to as an *income statement*, or as a profit and loss statement is used to monitor profits in a farm business from one year to the next. The income statement itemizes all farm income and all farm expenses. The fundamental indicators calculated in the income statement are net farm income from operations and net farm income.

Figure 4 illustrates an income statement for the 350-ha shrimp farm. Revenue is $3,819,888. Expenses are divided into cash and non-cash (depreciation) expenses. Thus, insurance and concession are included under Cash Operating Expenses along with variable costs. Accounts payable that have not been canceled and non-cash depreciation costs are added in to reach $2,732,203 total operating expenses. With the cash interest paid of $618,981, total expenses are $3,351,184. Net Farm Income From Operations is obtained by subtracting Total Expenses from Revenue to obtain $468,704. Any gain or loss from the sale of capital assets such as machinery or land would be used to adjust Net Farm Income From Operations to calculate Net Farm Income.

Monitoring solvency and liquidity

Solvency and liquidity are important financial measures of the overall well-being of a business. *Solvency* refers to the value of the assets owned by the business as compared to the amount of liabilities. *Assets*, of course, refer to the value of anything owned by the business whereas liabilities refer to any debt obligations that the business has outstanding. Liquidity refers to the ability of a business to meet cash flow obligations. *Liquidity* is critical to maintain smoothly running financial transactions of the business.

A financial instrument known as the *balance sheet* is used as the basis for measuring and monitoring solvency and liquidity in the farm business. The balance sheet lists all assets and liabilities for the business. Net worth is calculated on the balance sheet by subtracting the total value of all liabilities from the total value of all assets of the business. Net worth is also referred to as owner equity.

Figure 5 presents an example of a balance sheet for the 350-ha shrimp farm. The current assets include the cash, supplies on hand, and accounts receivable for the farm and total $105,000. Noncurrent assets list owned equipment and farm infrastructure. Total assets are $795,000. Current liabilities include the payments due in the first year for the shrimp farm. Noncurrent liabilities include the remainder of the equipment and pond construction loans. Total liabilities are $720,154.

Total owner equity is $74,846. Over time, the net worth should increase as the liabilities decrease and assets increase through equity gained with payments of principal.

Measuring Efficiency

Production and input use efficiency

Production efficiency refers to biological measures that are maintained by most farms. The key variables to use here would include measures such as yield of whole shrimp per hectare, yield of shrimp tails per hectare, survival, growth of shrimp, and others as listed in Figure 1b. Input use efficiency measures can also be used to evaluate farm efficiency. The feed conversion ratio is the most important measure of input use efficiency, but similar measures can be calculated for labor, utility use, and other inputs. The farm manager should review these types of measures at least once a year and compare them with previous years. This chapter will concentrate on economic and financial measures and will not go into production or biological efficiency measures.

Financial efficiency

Financial efficiency measures are designed to measure solvency and liquidity and to identify weaknesses in structure or mix of types of assets and liabilities. The primary sources of data to calculate financial measures are the balance sheet and the income statement.

Solvency

Solvency refers to the value of assets owned by the business compared to the amount of liabilities owed. Common measures of solvency include the following:

Debt/asset ratio The debt/asset ratio is a common measure of business solvency. It is calculated by dividing total farm liabilities by total farm assets using current market values for each.

$$\text{Debt/asset ratio} = \frac{\text{total farm liabilities}}{\text{total farm assets}}$$

Smaller values are preferred to larger ones. Smaller values indicate a better chance of maintaining the solvency of the business should it be faced with a period of adverse economic conditions. Low debt/asset ratios may also indicate that a manager is reluctant to use debt capital to take advantage of profitable investment opportunities. In Figure 6, the debt/asset ratio for the example 350-ha shrimp farm is 0.91. This value is less than 1 and indicates a solvent business. While somewhat high, this is typical of new farm businesses. This indicator should decrease as equity in the business grows.

Equity/asset ratio. The equity/asset ratio indicates what part of total assets is financed by the owner's equity capital.

$$\text{Equity/asset ratio} = \frac{\text{total equity}}{\text{total assets}}$$

Higher values of the equity/asset ratio are preferred, but the value of this ratio cannot exceed 1. If the equity/asset ratio = 1, liabilities then must be 0. An insolvent business would have a negative equity/asset ratio because equity would be negative. The equity/asset ratio for the 350-ha farm in Figure 6 is 0.09. There is very little equity in this business. This example is for a new business with a high debt load. Over time, as the loans are paid off, equity will increase in relation to the level of assets.

Debt/equity ratio. The debt/equity ratio is also called the leverage ratio. The debt/equity ratio compares the proportion of financing provided by lenders with that provided by the business owner.

$$\text{Debt/equity ratio} = \frac{\text{total liabilities}}{\text{total equity}}$$

When the debt/equity ratio = 1, lenders and owner are providing an equal amount of financing. Smaller values of the debt/equity ratio are preferred. The debt/equity ratio will approach zero as liabilities approach zero. Very large values result from very low equity, which means an increasing chance of insolvency. The debt/equity ratio for the 350-ha shrimp farm in Figure 6 is 9.62. In this example farm, there is very little equity because the majority of the capital is borrowed. Thus, this high value indicates a relatively high level of financial risk in the early years of the business.

Change in net worth. A change in net worth indicates business growth, additional capital investment, and a greater borrowing capacity.

$$\text{Net Worth} = \text{Total Assets} - \text{Total Liabilities}$$

The owner would want to see net worth increase over time.

Liquidity

Liquidity is the ability of a business to meet cash flow obligations. Liquidity is important to keep financial transactions of the business running smoothly. Common measures of liquidity include the following:

Current ratio. The current ratio is a quick indicator of a firm's liquidity. Current assets will be sold or turned into salable products in the near future and will generate cash to pay debt obligations that come due.

$$\text{Current Ratio} = \frac{\text{current farm assets}}{\text{current farm liabilities}}$$

The higher the value of the current ratio, the more liquid. The current ratio is 1.28 for the 350-ha farm in Figure 6. In future years, this value should increase because shrimp inventories will increase asset levels and payments on debt will lower liability levels.

Working capital. Working capital is the difference between current assets and current liabilities. It represents excess dollars available from current assets after current liabilities have been paid. Working capital for the example farm in Figure 6 is $22,704. This value will increase as growth of the shrimp crop increases asset values.

Profitability

A business that is both solvent and liquid will not necessarily be profitable. Profitability is calculated generally by subtracting total costs from total revenue. It is measured from the income statement. However, net farm income can be further partitioned into returns or profits attributable to each of the four primary factors of production: land, labor, capital, and management. Returns to capital can be further partitioned into returns to equity capital (capital owned by the farmer).

Net farm income. Net farm income measures the return to operator's equity, capital, unpaid labor, and management. It is measured from the income statement. Net farm income is measured as follows:

(Total revenue - total expenses) = net farm income from operations +/- the gain or loss on the sale of capital assets = net farm income.

The gross farm revenue "pie" can be divided among the parties who supply resources to the farm business.

Return to labor and management. The return to labor and management is what remains from net farm income after charging out returns for the use of all capital. Some businesses have more assets or borrow more money than others.

Return to labor and management is calculated as follows:

(Net farm income from operations + interest expenses) = (adjusted net farm income - opportunity cost of capital)

The returns to labor and management can be further partitioned into returns to either labor or returns to management. These measures indicate whether net farm income was sufficient to provide a return at least equal to the opportunity costs of labor and management. Return to labor is calculated as:

Return to labor and management - opportunity cost of management = return to labor

Returns to labor for the 350-ha shrimp farm in Figure 6 are $761,485. This is a very positive return to the labor resources used.

Return to management. Return to management is that portion of adjusted net farm income remaining after opportunity costs of both labor and capital have been subtracted. It represents a residual return to the owner for the management input. Negative returns to management are not unusual, but positive net returns should be the goal. Returns to management are calculated as:

(Return to labor and management - opportunity cost of labor) = return to management.

Returns to management for the 350-ha shrimp farm are $776,485 (Figure 6). These are very positive returns to the management resource used.

Rate of return on farm assets (ROA). The Rate of Return on Farm Assets can be compared to rates of return on other long-term investments. It is calculated as follows:

$$\text{Rate of return on assets (\%)} = \frac{\text{return to assets}}{\text{average farm asset value}} \times 100$$

The ROA is independent of the type and amount of financing. It can be compared to other similar farms, returns from other investments, opportunity costs of the farm's capital and past ROA's for the farm to measure profitability.

Return to assets is calculated as follows:

(Adjusted net farm income - opportunity cost of unpaid labor - opportunity cost of management) = (return to assets)

In Figure 6, the rate of return on farm assets is 129%. This high return is due to the fact that assets used are low compared to the amount of returns.

Rate of return on farm equity (ROE). The Rate of Return on Farm Equity is more indicative of the farm's financial progress. It measures the percent return to owner's net worth or equity. If the farm has no debt, the Return on Equity is equal to the Return on Assets. It is calculated as:

$$\text{Rate of Return on Equity (\%)} = \frac{\text{return on equity}}{\text{average equity}} \quad \text{x } 100$$

The return on equity is calculated as follows:

(Net farm income from operations - opportunity cost of unpaid labor - opportunity cost of management) = return on equity.

The rate of return on equity in Figure 6 is 540%. This high rate reflects the small amount of equity in the first year of the business.

Operating profit margin ratio. The operating profit margin ratio measures the proportion of gross revenues left after paying expenses. It is calculated as:

$$\text{OPMR} = \frac{\text{return to farm assets}}{\text{gross revenue of farm}}$$

The higher the value, the more profit the business is generating per dollar of revenue. Farms with large investments in fixed assets such as land and few operating expenses will show a higher OPMR. Farms with more rented assets will have a higher ROA but a lower OPMR. The only problem is if both ROA and OPMR are below average, then problems of profitability are evident. The operating profit margin ratio is 0.268. This indicates that, for every dollar of revenue, 26.8 cents remained as profit after paying the operating expense needed to generate that dollar.

Cash flow

There are financial considerations that can be as important to the economic feasibility of a business as profitability. Positive cash flow can often make the difference between success and failure of an aquaculture business, especially in the early years of a business start up.

A cash flow budget is one of the most useful financial instruments. It provides critical insights into whether the business will have adequate cash available when needed to meet its financial obligations. It can be used to evaluate borrowing needs and to determine cash needed to repay any new loans.

Cash flow budgets can be structured differently depending upon the purpose for which the analysis is being developed. For detailed financial planning, monthly cash flow budgets are useful. Quarterly budgets can be used to develop estimates of cash flow needs over a several-year period. Annual cash flow budgets are used in investment analyses to determine cash flow over the life of the investment.

There are certain key principles to keep in mind when constructing a cash flow budget. As trite as it may seem, it is important to keep in mind that only cash inflows and outflows are considered. No non-cash revenue or non-cash expenses are considered. Thus, a cash flow budget cannot be used to measure profit. The enterprise budget or the income statement is used to measure profit, not the cash flow budget. For example, depreciation is not included in the cash flow budget, but payments of principal and interest on all loans is. Inventory values are not included, but the proceeds from sales of any capital assets are included.

A primary concern in the cash flow budget is the timing of receipt of revenue and of expenses. Each type of revenue or expense is charged during the specific period when it is incurred. Thus, if a major capital asset is purchased during a given period, it is charged at that time in its entirety.

The cash flow budget begins with a beginning cash balance or the amount of cash on hand at the beginning of the period. This is followed by each source of farm cash revenue generated by sales of the crop or of other capital assets. The cash revenue items are summed to generate total cash inflow for the time period.

The expenses itemized first are the operating expenses. This is followed by expenses associated with the purchase of capital assets such as equipment or breeding stock. When the cash flow budget is to be used for applying for financing for loan, family living expenses are also included. The next section on expenses includes principal and interest payments for each separate loan. All expenses are summed to calculate total cash outflow.

The difference between total cash inflow and total cash outflow is the cash available. If the cash available is negative, this means that there is insufficient cash generated during the period to meet all cash obligations and additional borrowing is needed for that time period. After adding in the new borrowing, the cash balance is obtained. Cash balance becomes the beginning cash available at the start of the next time period.

At the bottom of the cash flow budget, it is useful to keep an accounting of the debt outstanding for each loan. In this manner, principal payments in a time period can be subtracted out of the balance owed.

Figure 7 presents a cash flow budget for the 350-ha shrimp farm example. This is a quarterly budget describing the cash inflows and outflows during a typical business year. Two production cycles are conducted per year. The dry-season growout cycle starts in middle January (Quarter I) and it is terminated in middle April (Quarter II) whereas the rainy-season cycle goes from early June (Quarter II) to late September (Quarter III). Most operating expenses associated with each production cycle are incurred in the first and third quarters, respectively. However, receipts from shrimp sales are recorded in the second and fourth quarters. Living expenses amount to $10,000 per quarter. Annual payments of Real Estate and Equipment loans are scheduled for the first and third quarters, respectively.

Because most of operating expenses and shrimp sale receipts occur in different quarters, cash deficits are recorded in the first and third quarters (the respective Cash Available values are negative). The ending Cash Balance must be always positive and, in this particular example, higher than $10,000 (this quantity is not a fixed rule). New operating loans must be made in the first and third quarters to cover the respective cash deficits. These loans must be re-paid as soon as possible, with interest charges being calculated over the lifetime of the loan. For instance, the Debt Outstanding on operating loans at the end of the first quarter is $968,692 (Figure 7). This amount includes a carryover debt from the preceding year ($196,912) and a new loan made in the same first quarter ($771,781). The cash inflow generated by the first production cycle is more than sufficient to cover the operating expenses of the second quarter. Then, it is possible to make a partial payment ($596,912) of the Debt Outstanding on operating loans in the second quarter. This payment covers first the carryover debt from the preceding year ($196,912) and $400,000 of the first-quarter loan. Assuming that the carryover debt ($196,912) was incurred in the last quarter of the preceding year and the interest rate is 36%, interest charges are calculated as follows:

Carryover debt:	$196,912	x 36% x 6/12 of a year =	$35,444
First-quarter loan:	$400,000	x 36% x 3/12 of a year =	$36,000
Total	$596,912		$71,444

Notice that the lifetime of each individual loan depends on the amount of time elapsed until loan re-payment. For instance, interest charges for the carry-over debt are calculated over a period of 6 months because the payment is made at the end of the second quarter. Notice also that a Debt Outstanding remains at the end of the second quarter ($371,781) because receipts are not sufficient to make a complete payment of this debt. The Cash Balance at the end of the second quarter is $37,785, which is used as the Beginning Cash of the third quarter. Since there are no shrimp sales in this quarter, Cash Available will be negative, and a new short-term loan must be made. The accumulated Debt Outstanding of the loans on operating capital is re-paid in full during the fourth quarter with the cash receipts generated by the rainy-season production cycle.

Compiling a business plan

A carefully prepared and well-thought out business plan is an essential step in either initiating or monitoring the financial performance of a business. There are two major components of a business plan: the marketing plan and the financial analysis.

The marketing plan is often the most overlooked component of a business plan. Many growers focus on the technical aspects of fish production and do not spend time considering market opportunities. Yet the most successful aquaculture businesses often are those that are market-oriented, have diverse markets, and are committed to their customers.

A potential producer should begin by talking to all local retail operations that handle the aquatic crop to be raised. Even if the grower intends to sell strictly to a processing plant, it is important to understand the product qualities and characteristics expected by the retail operators and end consumers. For those who intend to sell directly to a processing plant, some key considerations are:

1. Historical prices paid.
2. Dockage rates (poundage or percentage deducted from the total delivery rate) for trash-fish, out-of-size product, etc.
3. Transportation charges.
4. Payment frequency to growers.
5. Delivery volume requirements.
6. Quality standards, procedures, and requirements including flavor scores, sizing, and meat quality.
7. Delivery quotas and scheduling patterns for delivering product.
8. Availability of delivery contracts.

The business plan should include a thorough discussion of the proposed production system. Stocking rates, post-larvae sources, anticipated feed rates, and aeration strategy need to be presented clearly and consistently. For example, the feed rate should be appropriate for the stocking rate; low stocking rates do not require intensive aeration. Possible production problems such as disease occurrence should be mentioned.

There are many excellent books on the preparation of a business loan proposal on farm management, and on the financial analysis of agricultural businesses.

The business plan should include the following financial statements:

1. Annual estimated costs and returns. Also known as an enterprise budget, this statement is described above.

2. Estimate of required financing. The business proposal must clearly summarize financing requirements for the fish farm. Required financing should be divided into the following loan categories: operating, equipment, and real estate. The amount of capital for an operating loan is based on the amount of variable cost required. Equipment loans cover the purchase of any new or additional equipment necessary, while a real estate loan covers the cost of constructing ponds, buildings, or other relatively permanent structures. Repayment schedules should be specified to demonstrate how revenues will cover debt payments.

3. Proforma Balance Sheet. This statement is described above. Minimum standards used by lenders to evaluate the current ratio (also referred to as working capital on current position asset/liabilities) range from 1.3 to 1.5 with the higher level being preferred.

4. Proforma Income Statement. This statement is described above in detail.

5. Proforma Cash Flow Budget. This statement is described in detail above. Cash flow budgets need to be prepared for each year of the life of equipment that is financed. Family living expenses should be included in the cash flow budget to ensure that the need for income for family support does not conflict with business cash needs.

6. Personal financial statement. This is only required for business plans that will be used to request a loan.

7. Brief resume of borrower. This is only required for business plans that will be used to request a loan. Operating capacity and management skills will be critical to the success of the shrimp business. If the owner does not have these skills, the business proposal must include funds to hire a manager.

In evaluating a business plan and loan application, lenders will take into consideration several factors. The overall character and honesty of the individual is considered. Owner equity, the current ratio (from the balance sheet), the loan to appraisal value, and the value of farm production are key indicators for many lenders. Earnings will be examined in great detail along with repayment capacity. These will be viewed in terms of sustaining production over a three-year price cycle. Collateral and capital of the individual operator will also affect the level of the lender's decision.

Investment analysis

Capital on a farm or other business can be used in two general types of investments:

1. Operating inputs
2. Capital assets such as land, machinery, buildings, and orchards.

Analytical methods used to evaluate the two different types of capital use need to be different because timing of expenses and returns is different. Production inputs have expenses and returns typically within one year or less whereas investments in capital assets mean large initial purchases and then additional operating expenses and returns spread over a number of future time periods. Investment refers to the addition of intermediate and long-term assets to business. These types of assets have long-lasting consequences.

Three principle indicators of investment returns will be presented:

1. Payback period
2. Net present value
3. Internal rate of return

Payback period

The payback period is the number of years it would take for an investment to return its original cost through the annual net cash revenues it generates. If net cash revenues are constant each year, the payback period can be calculated as follows:

$$P = \frac{I}{E}$$

where: P = payback period in years
I = amount of investment
E = expected annual net revenue

Where annual net cash revenues are not equal, they should be summed year by year to find the year where the total is equal to the amount of the investment. The payback period can be used to rank investments according to the payback period (a shorter period is better). The payback has the advantage of being easy to use, and it quickly identifies investments with the most immediate cash returns. Disadvantages of the payback period are that it ignores any cash flows occurring after the end of the payback period and it ignores the timing of cash flows during the payback period. The payback period is more a measure of the investment's contribution to liquidity than to profitability. It is not the best method for evaluating the profitability of an investment. According to the annual cash flow budget presented in Figure 8, the payback period for the 350-ha shrimp farm would be 0.57 years. This is calculated from the average net cash flows over the 10-yr useful life of the ponds. Nevertheless, the cash flow budget shows that it would be well into the second year before this level of investment would be paid off.

Net present value

Net present value (NPV) is also known as the discounted cash flow method. Net present value is equal to the sum of the present values for each year's net cash flow less the initial cost of the investment. Present value (PV) is equal to the current value of a sum of money to be received or paid in the future. It is found using a process called discounting (future value discounted back to the present to find the present value). It is equal to the sum of present values for each year's net cash flow less the initial cost of the investment. It can also be viewed as that sum of money which would have to be invested now at the given interest rate to equal the future value on the same date (interest rate is called the discount rate). Compounding and discounting are opposite or inverse procedures. A present value is compounded to find its future value and a future value is discounted to find its present value. Mathematically, NPV is calculated as follows:

$$\mathbf{NVP} = \frac{P_1}{(1+I)^1} + \frac{P_2}{(1+I)^2} + \ldots\ldots + \frac{P_n}{(1+I)^n} - C$$

where: NVP = Net Present Value
P_n = net cash flow in year n
I = discount rate
C = initial cost of investment

Investments with a positive net present value would be accepted; those with a negative NPV rejected and zero value makes the investor indifferent. With a positive NPV, the rate of return of the investment is higher than the discount rate used, and it is greater than the opportunity cost of capital used as the discount rate. The limitations of the NPV analysis are that it depends on the discount rate and that it does not determine the actual rate of return. The NPV for the 350-ha shrimp farm is $2,996,123, using a discount rate of 20% (Figure 8).

Internal rate of return (IRR)

The internal rate of return is the actual rate of return on the investment with proper accounting for the time value of money. It is also called the Marginal Efficiency of Capital or Yield on Investment. The equation used is that for the NPV, but the equation is solved for I, the interest rate when NPV = 0. This equation is actually difficult to solve. It requires trial and error, but it can be solved through Microsoft EXCEL and other programs. Its interpretation is that any investment with an IRR greater than the opportunity cost of capital is profitable. Some investors select an arbitrary cutoff point. Unlike the NPV, it can be used to rank investments which have different initial costs and lives. The limitation of the IRR is that it implicitly assumes that annual net returns or cash flows can be reinvested to earn a return equal to the IRR. If IRR is fairly high, this may not be possible and the IRR may overestimate the actual rate of return. The IRR calculated for the 350-ha shrimp farm in Figure 8 was 98%. Since this is higher than the 20% interest rate on savings accounts prevalent in Honduras (which would equate to the opportunity cost of capital), the conclusion would be that the investment in this farm operation would be a profitable investment.

Linear programming

Linear programming is a computational procedure used to determine the best allocation of scarce resources in order to maximize income or minimize production costs of a specific commodity. It is a very popular tool used in agricultural economics research. Examples of how linear programming can be used in an aquaculture context to determine include:

1. The best possible use of scarce resources such as land, labor, feed, seed, etc. in the production of a single species.

2. The best possible use of scarce resources in the production of several species.

3. The exact composition of an animal diet which can satisfy all nutritional require ments at the least possible cost.

4. The optimal distribution pattern of a product among several geographic markets.

There are several assumptions underlying the concept of linear programming:

1. **The goal**: in agriculture-related programs, the most common objectives are income maximization or cost minimization of one or several commodities.

2. **Constraints**: linear programming is meaningless if resources are not limited. In a farm, restrictions may occur with respect to the production resources (land, labor, capital, etc.), managerial abilities of the owner, or market limitations.

3. **Alternatives**: several alternative ways must be available for attaining the objective. Otherwise, linear programming is not an efficient method to determine optimal conditions for the enterprise.

4. The relationship between quantity of resources and quantity of output must be linear and constant.

5. Costs and prices are constant, i.e., they are not dependent on input quantities or output levels.

Methodology

To properly define and solve a linear programming problem, excellent production records and budget information should be available. First, a complete inventory of all existing resources in the aquaculture farm (land, water, capital, seed, feed, labor, equipment) must be carried out. Next, the farm manager must make a decision as to which activity or group of activities are to be undertaken. The activities can refer to the production of several species or different ways to produce the same species. The next step is to develop a budget for each production activity, which must account for all expenses incurred and income generated per budgetary unit. This information is used to define the objective and constraint equations. As an example, a hypothetical income maximization problem is presented below.

Example

Suppose that three inputs (X_1, X_2, X_3,) are used to produce two outputs (Y_1, Y_2). It has been determined that producing one unit of Y1 requires two units of X_1, one unit of X_2, and three units of X_3; whereas producing one unit of Y2 requires two, two, and one units of X_1, X_2, and X_3, respectively (Figure 9). The total quantity of input units will determine the quantity of output units that can be produced.

The 40 units of X_1 can be used to produce Y_1, Y_2, or a combination of both outputs. Thus, we have that $2Y_1 + 2Y_2 \leq 40$. This means that, regardless of the chosen values for Y_1 and Y_2, the amount used of X_1 can not exceed 40, but it can be less than 40. The numbers (2, 2) on the left side of the equations are the coefficients of the production function. In linear programming terminology, these equations are called constraints. Three constraints have been defined in this example, one for each input.

$$2Y_1 + 2Y_2 \leq 40$$
$$1Y_1 + 2Y_2 \leq 36$$
$$3Y_1 + 1Y_2 \leq 30$$

Two additional constraints need to be defined:

$$Y_1 \geq 0,\ Y_2 \geq 0$$

These two restrictions need to be specified because otherwise the solution of the problem could indicate negative quantities.

The last equation to be defined is the objective function. This is an income maximization problem, and total net income in this example is calculated as follows:

$$\textbf{Net income} = I_{y1}Y_1 + I_{y2}Y_2 = \$2\,Y_1 + \$1\,Y_2$$

In summary, the objective of this linear programming model is to maximize the value of the objective function subject to the specified set of constraints.

Resolution of Linear Programming Models

The resolution of linear programming problems involves complex algebraic procedures if the number of production activities or constraints is high. Fortunately, there are a number of computer programs that allow the development and resolution of gigantic models, which may be composed of hundreds, even thousands, of production activities and constraint equations. One of such programs is the Solver, which comes as an add-in program to Excel. The use of the Solver in the resolution of income maximization problems in shrimp farms is illustrated in the accompanying training manual, "Tools for Better Management Decision Making for Shrimp Farmers" (Engle and Valderrama 2001) is recommended and is available from the Central American University Press, Managua, Nicaragua. The manual demonstrates the use of linear programming with an example adapted from the following reference:

Hatch, U., S. Sindelar, D. Rouse and H. Pérez. 1987. Demonstrating the use of risk programming for aquacultural farm management: the case of *Penaeid* shrimp in Panama. Journal of the World Aquaculture Society 18:260-269.

Risk analysis through the use of risk software

The concept of risk in agriculture enterprises refers to the level of uncertainty under which the different farm operations are carried out. In aquaculture farms, risk can be introduced by many factors. For instance, a failure in the aeration systems may lead to lethal dissolved oxygen (DO) concentrations during the evening hours, resulting in a massive fish kill. Incidents of this type bring about a reduction in the expected production levels. Risk is then introduced as the farm manager sees gross receipts drop to a level that may be not sufficient to cover operating expenses. Repeated episodes of low DO concentrations could cause enormous financial losses, eventually leading to the closure of the operation.

Uncertainty about the technical aspects of aquaculture production is not the exclusive source of risk. Fluctuations in input and output prices can make the difference between profit and losses. Of course, a higher degree of variability in prices will translate into a higher degree of risk in the operation. Unfortunately, risk cannot be measured from the enterprise budgets because these budgets are based on average values and reflect the expected level of net income generated by the farm. Sensitivity analyses represent an approach to measure risk. These analyses evaluate at what degree enterprise profitability is affected by changes in specific budget items. However, this type of analysis demands considerable time and effort, particularly if one wants to evaluate the effect of two or more changes.

Fortunately there are a number of commercially-available software products that allow the user to incorporate a variability component into spreadsheet-based enterprise budgets, and to measure the resulting risk level. One of such programs is Crystal Ball™, which functions as an add-in program to regular spreadsheets. The use of Crystal Ball as a risk analysis tool will be illustrated in the accompanying training manual, "Tools for Improved Management Decision Making for Shrimp Farmers" (Engle and Valderrama 2001) is recommended and is available from the Central American University Press, Managua, Nicaragua.

Figure 1a. Enterprise budget for a 350-ha shrimp farm in Honduras. Cost and price information is given in U.S. Dollars (1 Dollar : 13 Lempiras, 1997 exchange rate) and was obtained in part from a 1997 farm survey.

Item	Description	Unit	Quantity	Price/ unit ($)	Total cost ($)
Gross Returns					
Shrimp	Size 71-90	lb	337,198	3.25	1,095,894
	Size 41-50	lb	672,591	4.05	2,723,993
Total Gross Returns					3,819,888
Variable Costs					
Post-larvae (PL)	Hatchery	1,000	105,000	5.00	525,000
Feed	25% protein	hundredweight	24,859	23.08	573,746
Fertilizer	Urea 46%	hundredweight	325	8.62	2,802
	18-46-0	hundredweight	80	13.85	1,108
	$(NH_4)_2SO_4$	hundredweight	1,050	7.69	8,075
Chemicals	Chlorine	hundredweight	25	126.92	3,173
	Alcohol	gallon	9	5.85	53
Labor[a]		annual wage	70	2,215.38	155,077
Diesel[b]		gallon	43,631	1.15	50,176
Gas		gallon	3,400	1.80	6,120
Equipment repairs		dollars			76,923
Levee repairs		dollars			153,846
Post-harvest handling	Ice	lb of shrimp tails	1,009,789	0.03	30,294
	Hauling	lb of shrimp tails	1,009,789	0.03	30,294
	Processing	lb of shrimp tails	1,009,789	0.50	504,895
Marketing	Broker fees	lb of shrimp tails	1,009,789	0.20	201,958
	Sea freight	lb of shrimp tails	1,009,789	0.13	131,273
	Export fees	lb of shrimp tails	1,009,789	0.03	30,294
Interest on operating capital[c]	36%	dollars	1,591,186	0.36	572,827
Total variable costs (TVC)		dollars			3,057,934
Returns above TVC		dollars			761,954
Fixed costs					
Depreciation		dollars			177,824
Interest on investment		dollars			46,154
Insurance		dollars			70,000
Concession		ha	500	1.54	770
Total fixed costs (TFC)		dollars			294,748
Total cost (TC)		dollars			3,352,682
Net returns		dollars			467,206
Net returns per unit area		dollars/ha			1,335
Breakeven price at 2,885 lb/ha					
above TVC		dollars/lb			3.03
above TC		dollars/lb			3.32
Breakeven yield at $3.78/lb					
above TVC		lb/ha/year			2,311
above TC		lb/ha/year			2,534

a Calculation of annual wages is based on an average hourly wage of $0.92 and an average of 2,400 hours/employee/year.
b Gallons of diesel = (volume of water/ha) x (% water exchange) x (1/capacity of pump in gpm) x (# pumping days) x (1/60 min) x (pump consumption of diesel/hr). Assumed capacity of pump station is 20,000 gpm with a diesel consumption rate of 3.8 gal/hr.
c It is assumed that a short-term loan is needed to cover 75% of all variable costs exclusive of marketing costs.

Figure 1b. Characteristics of two production cycles used in the development of an annual enterprise budget for a 350-ha shrimp farm in Honduras. It is assumed that all ponds are simultaneously stocked with shrimp PL during January and May (dry and wet seasons, respectively).

	Dry-season production cycle	Wet-season production cycle
Length (days)	96	120
Stocking density (PL/m^2)	15	15
Survival rate (%)	50	52
Average weekly growth rate (g/week)	0.65	1.00
Head-on harvest weight (g)	8.96	17.19
Tail yield (%)	65	65
Tail count	71-90	41-50
Shrimp price (US$/lb)	3.25	4.05
Pond yield (lb shrimp tails/ha)	963	1,922
FCR	1.8	1.5
Number of pumping days	64	85
Water exchange rate (%/day)	10	10

Figure 2a. Effect on net returns/ha and breakeven price above total cost of varying feed prices.

Feed price (US$/hundredweight)				
15.38	19.23	23.08	26.92	30.77
		Net returns/ha		
2,029	1,682	1,335	988	641
		Breakeven price (US$/lb)		
3.08	3.20	3.32	3.44	3.56

Figure 2b. Effect on net returns/ha and breakeven price above total cost of varying survival rates.

Survival rate in each production cycle				
20%	35%	50%	65%	80%
		Net returns/ha		
-2,178	-507	1,165	2,836	4,508
		Breakeven price (US$/lb)		
5.71	4.03	3.36	3.00	2.77

Figure 3. Partial budget analysis used to evaluate the economic effect of introducing a new type of hatchery post-larvae (PL), which is assumed to exhibit higher survival rates but is priced at a superior cost (US$7/1000).

Additional revenue ($):		Additional costs ($):	
Shrimp	1,905,123	Post-larvae (PL)	210,000
		Feed	279,101
		Ice	14,911
		Hauling	14,911
		Processing	248,521
		Broker commission	99,409
		Sea freight	64,615
		Export fees	14,911
		Interest on operating capital	207,210
Reduced costs ($):		Reduced revenue ($):	
None.	-	None.	-
A. Total additional revenue and reduced costs ($)	1,905,123	B. Total additional costs and reduced revenue ($)	1,153,589
		Net change in profit - (A-B)	751,534

Figure 4. Income Statement for a 350-ha shrimp farm in Honduras.

Item	Value
Revenue	
Shrimp sales	$3,819,888
Expenses	
Cash operating expenses	
Post-larvae	525,000
Feed	573,749
Fertilizer	11,985
Chemicals	3,226
Labor	155,077
Diesel	50,175
Gas	6,120
Equipment repairs	76,923
Levee repairs	153,846
Post-harvest handling	565,483
Marketing	363,525
Insurance	70,000
Concession	770
Adjustments	
Accounts payable	-1,500
Depreciation	177,824
Total Operating Expenses	2,732,203
Cash Interest Paid	618,981
Total Expenses	3,351,184
Net Farm Income from Operations	468,704
Gain/loss on Sale of Capital Assets	0
Machinery	0
Land	0
Other	0
Net Farm Income	468,704

Figure 5. Balance Sheet for a 350-ha shrimp farm in Honduras.

Item	Value
Asset/Liability	
Current Assets	
Cash/checking account	$25,000
Marketable securities	5,000
Inventories	
Crops	0
Supplies	20,000
Accounts receivable	55,000
Prepaid expenses	0
Other current assets	0
Total Current Assets	105,000
Noncurrent Assets	
Machinery and equipment	250,000
Buildings and improvements	40,000
Land and ponds	400,000
Other noncurrent assets	0
Total Noncurrent Assets	690,000
Total Assets	795,000
Current Liabilities	
Accounts payable	24,000
Notes payable within 1 year	0
Current portion of term debt	12,142
Accrued interest	46,154
Total Current Liabilities	82,296
Noncurrent Liabilities	
Notes payable – equipment	238,166
real estate	399,692
Total Noncurrent Liabilities	637,858
Total Liabilities	720,154
Owner Equity	
Contributed capital	30,000
Retained earnings	44,846
Total Owner Equity	74,846
Total Liabilities and Owner Equity	795,000

Figure 6. Financial efficiency indicators for a 350-ha shrimp farm in Honduras.

1. Debt/asset ratio $= \dfrac{\text{total farm liabilities}}{\text{total farm assets}} = \dfrac{720{,}154}{795{,}000} = 0.91$

2. Equity/asset ratio $= \dfrac{\text{total equity}}{\text{total assets}} = \dfrac{74{,}846}{795{,}000} = 0.09$

3. Debt/equity ratio $= \dfrac{\text{total liabilities}}{\text{total equity}} = \dfrac{720{,}154}{74{,}846} = 9.62$

4. Net Worth = total assets - total liabilities =795,000 - 720,154 = 74,846

5. Current ratio $= \dfrac{\text{current farm assets}}{\text{current farm liabilities}} = \dfrac{105{,}000}{82{,}296} = 1.28$

6. Working capital = current assets - current liabilities = 105,000 - 82,296 = 22,704

7. Return to labor and management = net farm income from operations + interest expenses = adjusted net farm income (ANFI) - opportunity cost of capital

	468,704	
+	618,981	
ANFI	1,087,685	
-	286,200	(36% of total assets, 795,000)
	$801,485	

8. Returns to labor = return to labor and management - opportunity cost of management

	801,485
-	40,000
	761,485

9. Returns to management = returns to labor and management - opportunity cost of labor

	801,485
-	25,000
	776,485

10. Rate of return on farm assets = net farm income from operations + interest expenses - opportunity cost of unpaid labor - opportunity cost of unpaid management = Return to assets.

$$\frac{\textbf{Return to assets}}{\textbf{Average farm asset value}} \ \textbf{x 100} = \textbf{Rate of return on farm assets}$$

	468,704
+	618,981
-	25,000
-	40,000
	1,022,685

$$\frac{1,022,685}{795,000} \quad \text{x} \quad 100 = \quad 129\%$$

11. Rate of return on farm equity = (net farm income from operations - oppor tunity cost of unpaid labor - opportunity cost of management)= Return to equity.

Return to equity x 100 = Rate of return on farm equity

Average equity

	468,704
-	25,000
-	40,000
	403,704

$$\frac{403,704}{74,846} \quad \text{x} \quad 100 = \quad 540\%$$

12. Operating Profit Margin Ratio $= \dfrac{\text{return to farm assets}}{\text{gross revenue of farm}}$

$$\frac{1,022,685}{3,819,888} = 0.268$$

Figure 7. Quarterly cash flow budget for a 350-ha shrimp farm in Honduras. Values are given in U.S. Dollars.

Item	Quarter I (Jan-March)	Quarter II (April-June)	Quarter III (July-Sept)	Quarter IV (Oct-Dec)
Beginning Cash	10,000	10,000	37,785	10,000
Receipts	-	1,095,894	-	2,723,993
Cash Inflow	10,000	1,105,894	37,785	2,733,993
Operating Expenses				
Post-larvae (PL)	262,500	-	262,500	-
Feed	215,516	-	358,232	-
Fertilizer	5,993	-	5,993	-
Chemicals	1,613	-	1,613	-
Labor	38,769	38,769	38,769	38,769
Diesel	21,552	-	28,623	-
Gas	1,530	1,530	1,530	1,530
Equipment repairs	-	38,462	-	38,462
Levee repairs	-	-	-	153,846
Post-harvest handling	-	188,831	-	376,651
Marketing	-	121,391	-	242,133
Insurance	70,000	-	-	-
Total	617,473	388,983	697,260	851,390
Living Expenses	10,000	10,000	10,000	10,000
Other Expenses	-	770	-	-
Scheduled Debt Payments				
Real Estate Principal	419	-	-	-
Interest (36%)	143,889	-	-	-
Equipment Principal	-	-	16,094	-
Interest (36%)	-	-	85,740	-
Operating Principal	-	596,912	-	1,153,089
Interest (36%)	-	71,444	-	170,699
Total Cash Outflow	771,781	1,068,109	809,094	2,185,178
Cash Available	-761,781	37,785	-771,309	548,815
New Borrowing	771,781	-	781,309	-
Cash Balance	10,000	37,785	10,000	548,815
Debt Outstanding				
Real Estate	399,581	399,581	399,581	399,581
Equipment	250,000	250,000	233,906	233,906
Operating	968,692	371,781	1,153,089	-

Figure 8. Annual cash flow budget for a 350-ha shrimp farm in Honduras. Values are given in U.S. Dollars.

Item	Year 0[a]	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Beginning Cash		100,000	10,000	720,070	1,697,941	2,675,812	3,653,682	4,631,553	5,609,424	6,689,128	7,768,832
Receipts		-	3,819,888	3,819,888	3,819,888	3,819,888	3,819,888	3,819,888	3,819,888	3,819,888	3,819,888
Cash Inflow		100,000	3,829,888	4,539,958	5,517,829	6,495,699	7,473,570	8,451,441	9,429,311	10,509,015	11,588,720
Operating Expenses											
Post-larvae (PL)		-	525,000	525,000	525,000	525,000	525,000	525,000	525,000	525,000	525,000
Feed		-	573,749	573,749	573,749	573,749	573,749	573,749	573,749	573,749	573,749
Fertilizer		-	11,984	11,984	11,984	11,984	11,984	11,984	11,984	11,984	11,984
Chemicals		-	3,226	3,226	3,226	3,226	3,226	3,226	3,226	3,226	3,226
Labor		-	155,077	155,077	155,077	155,077	155,077	155,077	155,077	155,077	155,077
Diesel		-	50,175	50,175	50,175	50,175	50,175	50,175	50,175	50,175	50,175
Gas		-	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120	6,120
Equipment repairs		-	76,923	76,923	76,923	76,923	76,923	76,923	76,923	76,923	76,923
Levee repairs		-	153,846	153,846	153,846	153,846	153,846	153,846	153,846	153,846	153,846
Post-harvest handling		-	565,482	565,482	565,482	565,482	565,482	565,482	565,482	565,482	565,482
Marketing		-	363,524	363,524	363,524	363,524	363,524	363,524	363,524	363,524	363,524
Insurance		-	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000	70,000
Total		-	2,555,106	2,555,106	2,555,106	2,555,106	2,555,106	2,555,106	2,555,106	2,555,106	2,555,106
Living Expenses		40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
Other Expenses		770	770	770	770	770	770	770	770	770	770
Scheduled Debt Payments											
Real Estate Principal		308	419	570	775	1,054	1,433	1,949	2,650	3,604	4,902
Interest (36%)		144,000	143,889	143,738	143,533	143,254	142,875	142,359	141,658	140,704	139,406
Equipment Principal		11,834	16,094	21,888	29,767	40,483	55,057	74,878	-	-	-
Interest (36%)		90,000	85,740	79,946	72,067	61,350	46,777	26,956	-	-	-
Operating Principal		-	196,912	-	-	-	-	-	-	-	-
Interest (36%)		-	70,888	-	-	-	-	-	-	-	-
Total Cash Outflow		286,912	3,109,818	2,842,017	2,842,017	2,842,017	2,842,017	2,842,017	2,740,184	2,740,184	2,740,184
Cash Available		-186,912	720,070	1,697,941	2,675,812	3,653,682	4,631,553	5,609,424	6,689,128	7,768,832	8,848,536
New Borrowing		196,912	-	-	-	-	-	-	-	-	-
Cash Balance		10,000	720,070	1,697,941	2,675,812	3,653,682	4,631,553	5,609,424	6,689,128	7,768,832	8,848,536
Debt Outstanding											
Real Estate		399,692	399,273	398,704	397,929	396,875	395,442	393,494	390,843	387,239	382,337
Equipment		238,166	222,072	200,185	170,418	129,935	74,878	-	-	-	-
Operating		196,912	-	-	-	-	-	-	-	-	-
Net Cash Flow[b]	-650,000	-770	1,264,011	1,264,011	1,264,011	1,264,011	1,264,011	1,264,011	1,264,011	1,264,011	1,264,011

NPV = $2,996,123. IRR = 98%

[a] A Year 0 (Zero) is included to account for total investment costs (construction of ponds and buildings and acquisition of equipment).

[b] Values in the row "Net Cash Flow" are calculated as the difference between annual Receipts and the sum of Operating Expenses and Other Expenses. Living Expenses and Debt Payments are not included in this calculation. Net Cash Flow values are used in the calculation of NPV and IRR.

10

MANAGEMENT PRACTICES FOR REDUCING THE ENVIRONMENTAL IMPACTS OF SHRIMP FARMING

MANAGEMENT PRACTICES FOR REDUCING THE ENVIRONMENTAL IMPACTS OF SHRIMP FARMING

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There has been much discussion in recent years of the possible negative environmental impacts of shrimp farming. The main concerns are listed below:

- ✓ Mangrove destruction
- ✓ Pollution of natural waters with nutrients, organic matter and sediment
- ✓ Salinization of freshwater by pond effluents
- ✓ Use of bioaccumulative or toxic drugs, antibiotics, and other chemicals
- ✓ Over-exploitation of wild shrimp larvae for stocking ponds
- ✓ Wasteful use of fish meal
- ✓ Introduction of exotic species
- ✓ Spread of disease
- ✓ Loss of biodiversity in neighboring ecosystems

Examples of these adverse effects can be found, but they do not occur at all shrimp farms. Negative impacts usually result from bad planning and poor management. Two of the negative impacts, mangrove destruction and salinization of freshwater, can be avoided by good site selection and farm layout methods. Introduction of exotic species and over-exploitation of wild shrimp larvae can be prevented through the use of native culture species and acquisition of larvae from hatcheries. Attention to the four issues listed above also will protect biodiversity in neighboring ecosystems. The other concerns can best be addressed by better management practices. Thus, the remainder of this chapter will be devoted to describing environmentally- responsible management practices.

GOOD PRACTICES FOR SHRIMP POND MANAGEMENT

This discussion will begin with pond preparation for a new shrimp crop and continue until harvest. It will be restricted to semi-intensive shrimp culture without mechanical aeration as commonly practiced in Central America.

Pond preparation

When ponds are drained for harvest, nutrients and plankton are discharged, and the flocculent layer of highly organic material and many of the benthic organisms that occur near the soil-water interface are suspended and lost from ponds. It is common practice to dry pond bottoms after draining, and many times, bottom soils are baked dry before ponds are refilled. Therefore, when ponds are refilled with water and stocked to start a new crop, plankton and benthos that serve as natural food for postlarvae are scarce. Ponds need to be prepared by techniques for improving the abundance of natural food organisms for postlarvae before they are stocked. In this discussion, pond preparation refers to all activities that are done from the time a pond is drained for harvest until the postlarvae are stocked for the next crop.

Soil organic matter

Shrimp farmers are concerned about the excessive accumulation of organic matter in pond soils. Although this problem is probably less severe than often thought, monitoring of bottom soil organic matter concentrations can be useful for management decisions. The best time to sample pond bottom soils is soon after the pond has been drained, but before any soil treatments have been applied. Soil samples should be collected from several places in the pond bottom. It is adequate to take 10 to 12 random samples of the upper 5-cm layer and combine equal volumes of these samples to provide a composite sample for analysis. The composite sample should be mixed thoroughly, dried in an oven at 60 °C[1], and pulverized to pass a 20-mesh screen.

The best procedure for organic carbon determination is the oxidation of organic carbon by potassium dichromate and sulfuric acid (Walkley-Black Method) as described by Boyd and Tucker (1992). The standard procedure requires a modest amount of laboratory equipment, but the Hach Chemical Company, Loveland, Colorado, sells a portable soil organic carbon kit (Model CEL/700) based on the Walkley-Black Method that provides results comparable to those obtained with the standard Walkley-Black procedure (Queiroz and Boyd 1998a).

Soil organic carbon concentrations in bottom soils of shrimp ponds seldom exceed 1 or 2%, and values up to 3 or 4% are probably acceptable. Some organic matter in bottom soils is good because it favors benthic productivity. Ponds with less than 0.5% organic carbon may not have good benthic productivity. Organic carbon values can be multiplied by a factor of 2 to provide a rough estimate of actual organic matter concentration. Methods for accelerating the decomposition of soil organic matter are discussed below.

Drying

It is common practice to dry pond bottoms between crops. Drying accelerates the decomposition of organic matter accumulated in the bottom during the previous crop by providing better oxygenation to improve conditions for aerobic bacteria. Better oxygenation of

[1] If an oven is not available, samples can be spread in a thin layer on a plastic sheet or in a shallow plastic pan and dried quickly in the sun.

the soil also oxidizes reduced inorganic and organic compounds in the soil to improve soil condition. Moreover, drying kills disease organisms and their carriers that may exist in the soil. A drying period of 2 to 3 weeks usually is adequate. Longer drying periods deplete soil moisture and microbial activity declines. In wet weather, it may be impossible to adequately dry soil, but as a rule, pond bottoms should be dried well at least once per year (Boyd 1995).

Liming and disinfection

Application of agricultural limestone should be made to pond bottoms that are acidic (pH below 7). Agricultural limestone is pulverized limestone consisting of calcium carbonate ($CaCO_3$) or a mixture of calcium carbonate and magnesium carbonate ($MgCO_3$). Samples for soil pH may be collected and processed as described above in the subsection on "Soil Organic Matter". To measure pH, mix 10 or 20 g of dry, pulverized sample with 10 or 20 ml of distilled water, stir intermittently for 20 min and measure the pH with a glass electrode. Small, hand-held soil acidity testers can be injected into pond soils and a pH reading made directly. However, these devices are not accurate and should not be used by shrimp farmers. The application rate for agricultural limestone may be determined according to the following scale:

Soil pH	Agricultural limestone (kg/ha)
Above 7.0	0
7.0-6.5	500
6.5-6.0	1,000
6.0-5.5	2,000
Below 5.5	3,000

Agricultural limestone should be spread uniformly over the pond bottom. It should be applied within 3 or 4 days after ponds are drained and before the bottom soil becomes extremely dry. The limestone must dissolve in soil pore water [2] to increase soil pH and stimulate microbial activity. If soil is too dry, the limestone will not react to neutralize acidity.

In ponds where disease was a serious problem in the previous crops, the pond bottom can be treated with an agent to kill disease organisms and reduce the possibility of disease in the next crop. The most effective and economical way of disinfecting a pond is to apply burnt lime (calcium oxide, CaO) or hydrated lime (calcium hydroxide, $Ca(OH)_2$) to increase the soil pH above 10 and thus kill disease organisms (Snow and Jones 1959). A treatment rate of 1,000 kg/ha of burnt lime or 1,500 kg/ha of hydrated lime usually is sufficient for disinfecting pond bottoms (Boyd 1995). The lime must be spread uniformly over pond bottoms while they are still wet so that the lime will dissolve and penetrate the soil mass to raise pH and kill pathogens and their carriers.

2 Pore waters are the interstitial water found between soil particles.

Chlorination has been used to disinfect pond soils. However, organic matter in pond soils quickly reduces chlorine residuals to non-toxic chloride (White 1992), and as a result, 500 ppm of calcium hypochlorite may be needed for disinfection (Potts and Boyd 1998). To reach this concentration, about 1,000 kg/ha of calcium hypochlorite ($Ca(OCl)_2$) must be applied to the pond bottom. Thus, chlorination is much more expensive than lime treatment.

Tilling

Tilling of pond bottoms during the drying period can enhance oxygenation of the soil. Heavy-textured soils (clays and clay loams) will benefit more from tilling than will light-textured soils (sands, sandy loams, and loams). Tilling should be done with a disk harrow and limited to a depth of 5 to 10 cm. A rotor tiller also is suitable for tilling pond bottoms, but it is destructive to soil structure. Turning plows (breaking plows) require much more energy to use than disk harrows. Turning plows are useful when there is an excessive concentration of organic matter on the soil surface, because this plow turns the soil over to bury the surface layer under soil of lower organic matter concentration from deeper layers. Tilling should be done while bottom soils are still moist, but bottoms should be dry enough to support the weight of the tractor tires and prevent formation of ruts in the pond bottom.

Sediment removal

It usually is not necessary to remove sediment from ponds. However, if the interior canals (prestamos) fill in, or if particularly large amounts of sediment accumulate in deeper parts of ponds causing them to lose volume, sediment removal may be necessary. Sediment disposal should be done in such a way to prevent the sediment from washing into ponds or canals after heavy rains and to avoid adverse ecological impacts outside of ponds. Site specific methods of sediment disposal must be developed for each farm (Donovan 1997).

Disinfection of pond water

Because of the frequent occurrence of viral diseases in shrimp farming, many producers attempt to prevent viral particles or their carriers from entering ponds. The main methods are filtration of pond water or disinfection of pond water with chemicals such as chlorine gas, hypochlorous acid, formalin, ozone, or insecticides. The most commonly used insecticides are dipterex or sevin.

A filter will not remove virus particles, but if the filter bag is made of material with a mesh size of 250 or 300 microns, most virus carriers can be removed. It probably is not practical to filter the volumes of water necessary to fill large, semi-intensive shrimp ponds. The use of chemicals for disinfecting water is not effective in large ponds. It also is expensive, and the chemical may cause ecological damage. Thus, chemical disinfection of pond water should not be practiced under most circumstances.

Fertilization

Once the pond bottom has been dried and any other necessary soil treatments applied, the pond can be refilled. At this time, it usually is necessary to apply nutrients to encourage plankton and benthos, the natural food organisms of shrimp. The two key nutrients are nitrogen (N) and phosphorus (P). The common source of phosphorus is orthophosphate, but nitrogen may be supplied as urea, ammonia nitrogen, or nitrate. Urea quickly hydrolyzes to ammonia. Ammonia is undesirable in ponds for three reasons:

(1) it can be toxic to shrimp at relatively low concentrations;

(2) it is converted to nitrate by nitrifying organisms that produce hydrogen ion and lower the pH in the process; and

(3) nitrification requires a large amount of dissolved oxygen.

Thus, nitrate compounds have an advantage as nitrogen fertilizers because they are non toxic, they do not form acidity, and they do not have an oxygen demand. Moreover, nitrate is a source of oxygen to bacteria and when it is denitrified in ponds, it raises the pH slightly. Nevertheless, nitrate fertilizers are more expensive than other nitrogen fertilizers, and cost must be considered.

The best rates of nitrogen and phosphorus application for establishing a plankton bloom will vary with the availability of these two nutrients in pond soil and source water. A good application rate for general purposes is 2 to 4 kg/ha both of N and P_2O_5 (orthophosphate). We recommend that farmers purchase mixed fertilizer that already contains both nitrogen and phosphorus in the proper ratios rather than using fertilizer sources to mix fertilizers on the farm. Fertilizer applications should be made at 2-or 3-day intervals until a good plankton bloom is established.

Granular fertilizer should be premixed in pond water for a few minutes and the resulting slurry splashed over the pond surface. Within 2 weeks or less, the pond should have a good plankton bloom and benthos will have begun to grow. At this time, postlarvae should be stocked.

Some shrimp farmers like to apply manure to ponds to enhance plankton blooms. In our opinion, manure should never be used in shrimp ponds. Manures can cause low dissolved oxygen concentrations and deterioration of bottom soil condition. They also contain high concentrations of heavy metals, and they may contain antibiotics that can contaminate shrimp.

Of course, additions of organic matter can enhance the availability of benthos in ponds with low concentrations of organic matter in soil, and it is effective in encouraging rapid blooms of zooplankton (Geiger 1983). If one wants to use organic fertilizers, it is better to use plant meals rather than manures.
For example, a good organic fertilization program is to apply 500 kg/ha rice bran when

filling the pond. Afterwards, apply the rice bran at 5 to 10 kg/ha per day until shrimp are stocked. Other suitable organic materials are soybean meal, crushed grain, and low-cost chicken feed.

Stocking shrimp

After holding the water in the pond for about 2 weeks, virus particles in the water will have disappeared and a good plankton bloom and benthic community should have been esta-blished. Shrimp postlarvae to be used for stocking should be free of disease. This can be assured by careful examination for diseases including polymerase chain reaction (PCR) analysis for viral diseases such as white spot virus disease.

The environmental impact of shrimp farming can be reduced if farmers use postlarvae that are produced in hatcheries rather than wild caught postlarvae. It also is easier to obtain evidence of the disease-free status of postlarvae when they come from hatcheries rather than the wild.

Postlarvae should be native species, and if they are imported, all governmental regulations involving importations should be respected.

Maintenance of Productivity during Grow Out

Most shrimp ponds are supplied manufactured feed from stocking until harvest. The amount of feed applied depends upon the shrimp biomass, and the feeding rate increases as the grow-out period progresses. However, in semi-intensive shrimp production, feeding rates seldom exceed 20 kg/ha until the later part of the grow-out period.

Use of fertilizer can be beneficial in maintaining natural productivity. Good levels of natural productivity in ponds help maintain water quality, especially by providing dissolved oxygen through photosynthesis, by removing ammonia, and by enhancing natural food availability for shrimp to improve feed utilization and shrimp production.

In intensive ponds, it is often not necessary to fertilize after the first 6 or 8 weeks. In fact, fertilization of ponds with feeding rates above 20 to 30 kg/ha per day may encourage excessive phytoplankton blooms.

Fertilization

The objective of water quality management should be to maintain a moderate but stable phytoplankton bloom (Boyd and Tucker 1998). The best way to accomplish this is with an aggressive fertilization program of 1 to 2 kg N and 0.5 to 1 kg P_2O_5/ha per week. Some farmers prefer a high proportion of diatoms in the phytoplankton communities of shrimp ponds. There is evidence that a high nitrogen:phosphorus ratio encourages diatoms, and it is common practice to use only nitrogen fertilizer or a fertilizer with a wide nitrogen:

phosphorous ratio of 15 or 20 to encourage diatoms. We are not convinced that a high nitrogen: phosphorus ratio is as beneficial as claimed. Thus, we will not recommend this practice, but farmers may use it if they desire.

There are claims that nitrate is more efficient in promoting diatoms than other sources of nitrogen fertilizer. Moreover, there are reports that applications of silicate or silicate and chelated iron can stimulate diatoms in shrimp ponds. Although this is probably true in some situations, since we do not know the limiting concentrations of silicate and iron to diatoms in pond water, it is difficult to make recommendations as to which ponds need these treatments. Data on effective application rates of silicate and iron are also not available. Nevertheless, shrimp farmers may want to try applications of silicate and chelated iron to see if they increase diatoms.

Pond fertilizers should be applied according to the Secchi disk visibility to conserve nutrients, reduce costs, and prevent excessive phytoplankton. In our opinion, the best Secchi disk visibility range is 25 to 40 cm. If one is applying fertilizer weekly at the rate of 10 kg/ha, the following scale illustrates a way to adjust fertilizer application rates for Secchi disk visibility:

Secchi Disk (cm)	*Fertilizer (kg/ha)*
20	0
25	2.5
30	5.0
35	7.5
40	10.0

Liming

Unless the total alkalinity of pond water falls below 75 mg/L as equivalent calcium carbonate, agricultural limestone should not be applied to pond waters during the production period. Burnt or hydrated lime should never be applied to pond water during grow-out because they can cause high pH and possibly harm shrimp. In areas where pond waters have low alkalinity, total alkalinity should be monitored monthly.

Water exchange

Water analysis kits are available for measuring total alkalinity. If values drop below 60 mg/L, agricultural limestone should be broadcasted over pond surfaces at 500 kg/ha.

Water exchange has traditionally been used in shrimp ponds at rates of 10% to 15% of pond volume per day. It is difficult to justify the use of routine water exchange, because if pond water is of adequate quality, renewal of a portion of the pond water daily is of no benefit.

Also, water exchange flushes out nutrients and plankton, so it reduces natural productivity in ponds.

It is counterproductive to apply fertilizers to ponds for the purpose of enhancing phytoplankton productivity and then flush the nutrients from the ponds by exchanging water. Usually, there is no scientific reason to expect much benefit from routine, daily water exchange in semi-intensive shrimp ponds. The main exception is in ponds where salinity may rise to unacceptable concentrations during the dry season.

Exchanging water at 5% to 10% per day can maintain acceptable salinity during the dry season even where full-strength seawater is the only water source. Of course, when crises of low dissolved oxygen or high ammonia concentration occur, water exchange is often the only resort.

It is significant to note that water exchange is seldom used in other kinds of pond aquaculture. For example, in channel catfish farming in the United States, farmers once used water exchange just like many shrimp farmers do today. However, research and practical experience demonstrated that water exchange was not necessary.

Today, catfish farmers do not exchange any water, and they harvest fish with seines to conserve water in ponds. The only time water is discharged from ponds is after heavy rains, or when ponds must be drained to remove large fish that have escaped capture for several years, or to repair wave damage to inside slopes of embankments (Boyd et al. 2000).

There obviously are great benefits to reducing water use in shrimp ponds. Water conservation can reduce the amount of pumping capacity needed on a farm and the amount of energy used for pumping water thereby lowering costs. Retention of water in ponds lowers the quantity of fertilizer nutrients necessary to maintain natural productivity, and this also lowers the cost of shrimp production. A longer water retention time in ponds allows for greater assimilation of nutrients and organic matter within ponds, and this leads to enhanced effluent quality.

Lower water velocities will reduce erosion of earthwork and lessen concentrations of suspended solids in effluent. Conservative use of water in shrimp ponds reduces production costs and protects against pollution of coastal waters by reducing the volume and enhancing the quality of effluents.

Measuring productivity

Secchi disk. This device, a 20-cm diameter black and white disk, can be lowered into the water to estimate the depth of underwater visibility. It can be extremely valuable for monitoring plankton provided the limitations of the technique are understood. Turbidity in water restricts underwater visibility, and as turbidity increases, the Secchi disk readings decrease.

Turbidity in water can result from living plankton, dead particulate matter, dissolved organic substances, and suspended soil particles. In cases where changes in turbidity result from changes in abundance of living plankton, the usual case in shrimp ponds, the Secchi disk can reveal if plankton growth is increasing or decreasing.

Additional details about the Secchi disk and its use can be found in the, "Secchi disk visibility".

In most shrimp ponds, the Secchi disk visibility should be between 25 and 40 cm. When the value is greater than 40 cm, plankton bloom should be encouraged by adding fertilizer. At Secchi disk readings below 25 cm, fertilizer should not be applied because of the danger of excessive plankton causing low dissolved oxygen concentrations.

Phytoplankton abundance

Phytoplankton counts. Direct counts of the genera and abundance of phytoplankton often are made for waters of semi-intensive shrimp ponds. Green algae and diatoms are more suitable in shrimp ponds than blue-green algae and dinoflagellates. Thus, microscopic examination of the water can be an aid to determining if a desirable phytoplankon community is present. Enumeration of the phytoplankton is of less value because of the size variation of individuals of different taxons. A few large algae may represent more biomass than many small algae. Thus, it is difficult to evaluate data on the abundance of phytoplankton cells, filaments, or colonies, and the acquisition of such data is very time consuming. This practice is not recommended.

Chlorophyll α The amount of chlorophyll α in water can be measured by removing the particulate matter by filtration through a membrane filter, extracting the pigment from the phytoplankton on the filter with acetone or methanol, and estimating chlorophyll a by spectroscopy. The chlorophyll α concentration increases as phytoplankton abundance increases. Aquaculture pond water typically have 10 to 100 mg/L of chlorophyll α, but some ponds may have less or considerably more.

In semi-intensive shrimp ponds, chlorophyll α concentrations of 30 to 60 mg/L are probably best. Considerable expertise and costs are involved in chlorophyll α analysis, and we do not recommend this procedure unless a shrimp farm has a good water quality laboratory and a skilled technician.

Light-dark bottle productivity. In this procedure, three BOD bottles are filled with pond water from the same source. One bottle is called the initial bottle (IB) because its oxygen concentration is measured immediately. The second bottle is covered with black tape or painted to exclude light and is called the dark bottle (DB). The third bottle is called the light bottle (LB) because it is transparent to sunlight. The light and dark bottles are incubated in the pond for a specified period during daylight, and they are then removed and the dissolved oxygen concentration measured. Details on conducting light-dark bottle productivity measurements may be found in Boyd and Tucker (1992) and will not be discussed further.

There is a wide range of primary productivity in aquaculture ponds, but values for gross productivity typically should be between 5 and 15 mg/L per day. It is very important that the 24-hour net productivity be 2 to 4 mg/L because more dissolved oxygen must be produced each day than is used by the plankton community or the pond will suffer from dissolved oxygen depletion at night.

Measurements of primary productivity are probably the most reliable estimates of the activity of plankton communities in ponds. However, the expertise for making these analyses is not available on most shrimp farms.

Benthos

Measurements of benthic productivity are extremely tedious, and they are seldom practical to make on shrimp farms.

Feed management

Feed is one of the most expensive management inputs, and the feed nutrients that are not converted to shrimp flesh cause water quality deterioration in ponds. Feed ingredients also are important resources that should not be wasted. Thus, feed management is a critical aspect of environmentally-responsible shrimp culture.

Feed quality

The quality of feed is very important because high quality feeds are used more efficiently by shrimp and produce less waste in ponds. Feeds should be made of high quality ingredients that are not contaminated with pesticides or other agricultural chemicals. Feeds should contain an efficient binder to assure water stability so that shrimp can eat the feed particles before they disintegrate on the pond bottom. Feeds that contain a large proportion of small particles and dust (called fines) should be avoided because shrimp cannot eat these small particles.

Feeds also should contain no more nitrogen (nitrogen x 6.25 = crude protein) and phosphorus than necessary to satisfy shrimp dietary requirements. Excessive nitrogen and phosphorus in feeds will increase nitrogen and phosphorus inputs to water and encourage excessive phytoplankton blooms.

Shrimp feeds containing 20 to 30% crude protein are adequate in semi-intensive shrimp culture. Several trials on low protein feeds were conducted by Auburn University at shrimp farms in Honduras as part of the USAID, Pond Dynamics/Aquaculture Collaborative Research Support Program (PD/A CRSP). Unpublished results of these studies suggested that low protein feed can be just as efficient as high protein feeds in semi-intensive shrimp culture. Based on results of the PD/A CRSP studies, farmers may want to conduct trials with feed containing 20% or less protein. By using a low-protein content feed, the fish meal content of shrimp feeds can be reduced. However, care must be taken not to reduce nitrogen and phosphorus too much. If feeds are deficient in nitrogen (protein) and phosphorus, more feed will be required per kilogram of shrimp production. This will lead to higher organic matter inputs and impaired water quality. See Chapter 1.

Feed brought onto a shrimp farm should be stored in a dry, well-ventilated place to prevent mold. Feed should be used promptly and before the expiration date suggested by the manufacturer to protect its quality. Shrimp are able to utilize fresh feed that has been stored properly better than old or deteriorated feed, and less waste and pollution of the pond will result.

Feeding practices

Feed should be applied conservatively so that shrimp have an opportunity to consume as much of the feed as possible. This is an important economic consideration, and it also reduces the input of nutrients to ponds. Feed amounts should be based on feeding charts that take into account shrimp biomass.

Estimate of shrimp biomass should be made by frequent samplings with cast nets to determine growth rate. Feeding trays also can be used to ascertain if shrimp are eating most of the feed applied. Some farmers attempt to offer all feed on feeding trays, but this practice seldom is feasible in large, semi-intensive ponds.

Feed should be spread as uniformly over ponds as possible to prevent feed accumulation in specific locations on the pond bottom. Accumulation of feed on the bottom can result in deterioration of soil quality. If possible, feed should be offered more than once per day in order to increase the proportion of applied feed consumed by the shrimp.

Feeding rates above 30 to 40 kg/ha per day in un-aerated ponds without high rates of water exchange can lead to water quality deterioration. Thus, ponds should be stocked at rates that do not require high feed inputs.

Impaired water quality in ponds, and especially low dissolved oxygen concentration, stresses shrimp and they do not eat well. They also will be more susceptible to disease, convert feed to shrimp flesh less efficiently, and suffer greater mortality. Therefore, shrimp farmers should strive to maintain good water quality in ponds by maintaining moderate stocking, feeding, and fertilization rates.

When shrimp are stressed or diseased, they will not consume feed well. Therefore, during periods when shrimp are not eating well, feed inputs should be reduced to minimize waste. However, cloudy weather is not a good reason to reduce feed input if shrimp are eating well and dissolved oxygen concentrations are within the normal range.

The feed conversion ratio (FCR) is one of the most important variables in shrimp farming. Farmers should keep careful records of the amount of feed applied to each pond so that the

FCR can be calculated. The goal should be to reduce the FCR to as low a value as practical. In semi-intensive culture, it should be possible to obtain FCR values of 1.5 to 1.8. Farmers certainly should try to prevent FCR from rising above 2.0.

Water quality management

The most important means of preventing water quality deterioration in ponds during grow out is good feed management. If low dissolved oxygen concentration occurs during grow out in semi-intensive shrimp culture, the only means available to the farmer usually is to increase water exchange. Of course, increasing water exchange will increase the amounts of pollutants discharged from ponds. The alternative to water exchange for counteracting low dissolved oxygen concentration is mechanical aeration. Unfortunately, most semi-intensive shrimp farms do not have electrical services for operating electric aerators.

In the United States, tractor-powered emergency aerators are often used to prevent mortality of fish or shrimp when dissolved oxygen is low. These devices are much more effective than water exchange for combating crises of low dissolved oxygen concentration, and they can be moved from one pond to another as required.

It is not feasible to provide the technical details for fabrication of tractor-powered paddle wheel aerators in this report. However, tractor-powered aerators can be purchased from the United States, and they could be fabricated locally. A photograph of a tractor-powered paddle wheel aerator is provided (Figure 1).

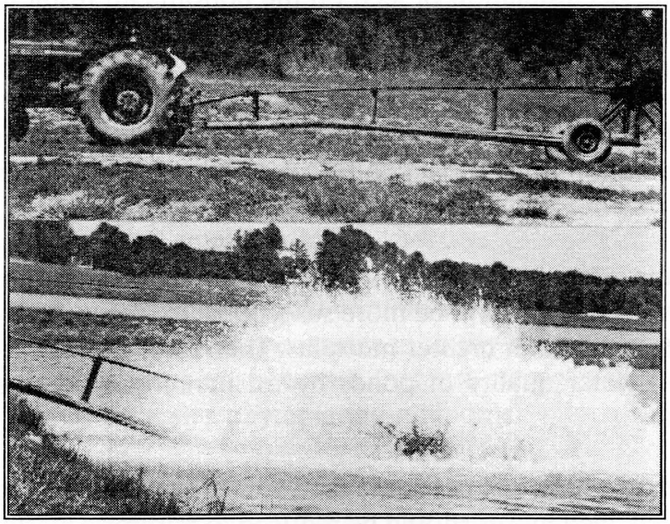

Figure 1. Tractor-powered paddle wheel aerator.

Many times, organic matter originating from uneaten feed and moribund phytoplankton or other plants accumulates in the corners of ponds. The material appears as a floating scum, but usually there is also accumulation of organic matter on the bottom beneath the floating scum. Water and soil quality deterioration in the corners of ponds can be prevented by periodic removal of the scum by manual means.

Use of drugs, antibiotics and other chemicals

Some farmers treat ponds with various chemicals when diseases occur in shrimp. These products usually have limited effectiveness and we recommend that they not be used unless it is absolutely necessary. This recommendation is based on the fact that some of these products may be toxic to aquatic animals in natural waters receiving pond effluents. Also, some of these products are bioaccumulative and residues could occur in shrimp harvested from ponds in which they were applied.

Some farmers insist upon or occassionally find it necessary to use medicated feed and other chemicals for disease control. If this practice is to be carried out, there should be a diagnosis of the disease and a specific chemical product known to be effective against the disease should be used. Use of the chemical should follow the manufacturers' instructions, and water should not be discharged from treated ponds until the chemical has been degraded by natural processes. All precautionary measures should be taken to assure worker safety such as use of protective gear whenever using chemicals.

Under no circumstances should chemicals banned in shrimp-importing countries be applied to shrimp ponds. Any chemicals used on farms should be stored in a secure area, and unused portions should be disposed of in an environmentally-responsible manner. The manufacturer should be consulted about proper disposal techniques.

Probiotics and other treatments

In Asia, a large number of chemical, physical, and biological treatments have been used for the purpose of enhancing water quality in ponds. These products include formalin, chlorine, benzylchromium chloride, provodone iodine, zeolite, peroxides, bacterial inocula, enzyme preparations, etc. Most of these products are not appropriate for use in large, semi-intensive ponds. Also, formalin, chlorine, and other strong chemicals have not been effective, and they could cause negative environmental impacts.

In the past few years, a class of products known as probiotics and consisting of bacterial inocula, enzyme preparations, and plant extracts have received increasing use in semi-intensive shrimp culture. To date, there is little evidence that these substances can significantly enhance soil and water quality in ponds or improve natural productivity (Boyd and Gross 1998). However, there is evidence that bacterial inocula and grapefruit seed extracts can improve survival of culture species (Queiroz and Boyd 1998b; Boyd and Gross 1998).

Much additional research is needed to elucidate the modes of action of these products and to determine how and when they can be used for the most benefit to shrimp production. Fortunately, there is no reason to suspect that probiotic use could result in negative environmental impacts.

In summary, there is not enough documentation of successful use of bactericides, oxidizing agents, zeolite, probiotics and other related products for us to recommend use of these substances. In particular, we do not recommend the use of strong chemical treatments such as chlorine, formalin, and insecticides that may cause negative environmental impacts.

Effluent management

Nutrients, organic matter, and suspended solids in effluents can cause negative environmental impacts in coastal waters. By reducing water exchange, the amount of effluent released during the crop can be greatly reduced. However, at present, technology for harvesting shrimp without draining ponds is not available and ponds must be drained to remove the crop. Possible means of reducing the concentration of potential pollutants in shrimp pond effluent are as follows:

- use good management practices during the grow-out period
- discharge the final 20 to 25% of the pond effluent as slowly as possible to minimize resuspension of solids from the pond bottom
- pass the effluent through a sedimentation basin
- construct, maintain, and operate drainage canals to minimize erosion of the sides of bottoms of these conduits
- prevent erosion at the final outfall of the farm (Boyd 1999).

Pond Management to reduce impacts of effluents

Nutrients in aquaculture pond effluents mainly come from fertilizers and feeds applied to ponds to stimulate the production of the culture species. Organic fertilizers, e.g., animal manures or other agricultural byproducts, are sometimes applied to ponds. These materials contain nitrogen and phosphorus that are released into the water as the organic fertilizer is decomposed by microbes.

Chemical fertilizers, e.g. urea, triple superphosphate, diammonium phosphate, mixed fertilizers, etc., dissolve in water to release nitrogen and phosphorus. Feeds also contain nitrogen and phosphorus. Some of the nitrogen and phosphorus in feeds enter the water when unconsumed feed and feces decompose, and more is added when ammonia is excreted by the culture species. Organic nitrogen and phosphorus are both present in the water as a component of living plankton and soluble organic matter. Inorganic nitrogen is dissolved in the water primarily as ammonia nitrogen and nitrate.

Inorganic phosphorus in water may be contained on suspended soil particles or in soluble phosphate. Phytoplankton and other plants use ammonia nitrogen, nitrate, and soluble inorganic phosphorus for growth. Nitrogen and phosphorus contained in dead particulate organic matter or soluble organic matter in the water may be transformed by microbial decomposition to ammonia nitrogen, nitrate, or phosphate. Because organic nitrogen and phosphorus can be transformed to soluble inorganic form by microbes, the eutrophication potential of pond effluents increases as the total concentration of nitrogen and phosphorus increases. In ponds with heavy plankton blooms, most of the nitrogen and phosphorus may be contained in plankton and detritus rather than in soluble form.

Pond effluents with low concentrations of ammonia nitrogen, nitrate, and phosphate, but with high plankton abundance, may still have as great a pollution potential as an effluent with high concentrations of ammonia, nitrate, and phosphate. This results because the organic matter (plankton, detritus, and soluble organic matter) that enters natural waters via pond effluent will decompose and release ammonia nitrogen, nitrate, and phosphate. Many shrimp farmers may not think that pond effluents contain much nitrogen and phosphorus because they do not use organic fertilizers. They use chemical fertilizers sparingly and only near the beginning of the culture period, and the feed conversion ratio is good.

Shrimp farmers may not understand the relationship between feed conversion ratio (FCR) and feeding wastes. The FCR is the weight of feed applied divided by the net weight of shrimp harvested. Some may think that an FCR of 1.5 means that 1.5 kg of feed will provide 1 kg of shrimp and generate 0.5 kg of waste. This would be a gross underestimate of waste generation in shrimp feeding.

The relationship among feed input, shrimp production, and waste generation will be analyzed more carefully. The feed used in aquaculture normally is a dry pellet. Shrimp feed contains about 90% dry matter and 10% water. Shrimp, on the other hand, contain about 25% dry matter and 75% water. Thus, in the production of 1 kg of shrimp with 1.5 kg of feed (feed conversion ratio of 1.5), 1.35 kg dry matter in feed yields 0.25 kg dry matter in shrimp. From an ecological point of view, 1.35 kg (1.5 kg feed x 0.9) dry nutritive substance has to be used to produce 0.25 kg (1 kg shrimp x 0.25) of dry matter in shrimp. Thus, the dry matter conversion ratio is only 5.4 (1.35 kg dry feed / 0.25 kg dry shrimp). The ratio of shrimp to wastes of 1:0.5 based on the usual method for estimating feed conversion ratio is an apparent ratio, but the true ratio based on dry matter is 1:4.4.

Suppose that a shrimp feed contains 35% crude protein and 1.2% phosphorus. Crude protein is estimated as percentage nitrogen multiplied by 6.25, so this feed has 5.6% N, and 1.5 kg of this feed contains 84 g nitrogen (1,500 g feed x 0.056) and 18 g phosphorus (1,500 g feed x 0.012). The 1 kg of shrimp produced by the feed will contain 0.25 kg dry matter, and the shrimp dry matter is about 11% nitrogen and 1.25% phosphorus. It follows that 27.5 g nitrogen (250 g dry shrimp x 0.11) and 3 g phosphorus (250 g dry shrimp x 0.0125) are contained in the shrimp.

The differences between the amounts of nitrogen and phosphorus in the feed and in the harvested shrimp represent the amount of nitrogen and phosphorus entering the pond water. In this example, each kilogram of live shrimp would result in 56.5 g nitrogen and 15 g of phosphorus in wastes. On a per ton basis, this would be 56.5 kg nitrogen and 15 kg phosphorus.

In a pond without water exchange, much of the nitrogen and phosphorus will be removed from the water. Nitrogen will be lost to the air by volatilization of ammonia and by microbial denitrification. Some nitrogen will be contained in organic matter deposited in the pond bottom, and phosphorus will be absorbed by sediment. Recent studies suggested that about 50% of the nitrogen and 65% of the phosphorus added in feed could be removed from the water of a pond without water exchange through physical, chemical, and biological processes. Considering that about 25 to 35% of the nitrogen and 15 to 25% of phosphorus added in feed is recovered in shrimp at harvest, only 15 to 25% of the nitrogen and 10 to 20% of the phosphorus applied in feed would be lost in effluent at pond draining. Of course, with water exchange, there would be a greater loss of nitrogen and phosphorus in effluents, because more nitrogen and phosphorus would be flushed out of ponds before being removed by natural purification processes within the pond. Even in a pond with zero water exchange, the loss of nitrogen and phosphorus at pond draining might be 12.6 to 21 kg nitrogen and 1.8 to 3.6 kg phosphorus where 1 ton of shrimp is produced at a feed conversion ratio of 1.5 (see example above). Thus, for different levels of production, the nitrogen and phosphorus outputs might be as follows:

Production (kg)	N (kg/ha)	P (kg/ha)
500	6.3-10.5	0.9-1.8
1000	12.6-21	1.8-3.6
2000	25.0-42	3.6-7.2
3000	37.8-63	5.4-10.8
4000	50.4-84	7.2-14.4

These outputs represent rather large amounts of nitrogen and phosphorus. The effluents from aquaculture can be a threat leading to eutrophication of natural waters into which they are discharged. Eutrophication is an increase of natural productivity caused by increased levels of nutrients, and in some cases, leading to algae blooms and low dissolved oxygen levels. Several measures can be taken to avoid or minimize eutrophication as follows:

- Minimize water exchange. By retaining water in ponds for a longer time, there is greater opportunity for removal of nitrogen and phosphorus by natural processes.

- Use a high quality feed. A feed that is water stable can be eaten more completely by shrimp. Also, a high quality feed results in less feces and metabolic waste.

- Use feeds with the lowest nitrogen and phosphorus concentrations that are compatible with good feed quality. This will minimize the amount of nitrogen and phosphorus in wastes.

- Feed conservatively. Overfeeding results in wasted feed and increases the amount of waste. It is important for the shrimp to eat all of the feed put into ponds for both economic and environmental reasons.

- When draining ponds, try to minimize the velocity of outflowing water so that sediment is not resuspended from pond bottoms. This practice will lower the amount of organic nitrogen and phosphorus in effluents by retaining organic particles with in the pond.

- Maintain good dissolved oxygen concentrations in ponds by not overstocking and feeding too much so that the pond can assimilate most of the wastes. The assimilative capacities of ponds differ, and aerated ponds can assimilate much more waste than unaerated ponds. Good dissolved oxygen concentrations favor oxidation of ammonia to nitrate and nitrate can then be denitrified in the sediment.

- Dry pond bottoms and lime acidic bottom soils between harvests to favor organic matter decomposition. This will reduce the accumulation of organic matter in bottom soils. Less organic matter at the beginning of the crop will reduce the likelihood of poor soil quality later in the crop.

Settling basins

Although water exchange rates tend to be lower than in the past, most shrimp farms still exchange some water. In fact, the greatest volume of effluent normally results from water exchange. When a 1-m deep pond is drained for harvest, 10,000 m^3 of effluent are released per hectare. For comparison, the amount of effluent from different average water exchange rates during a 120-day grow-out period are provided below:

Average daily water exchange (% pond volume)	Exchange effluent volume (m^3/ha per crop)
2	24,000
5	60,000
10	120,000
15	180,000

At a low water exchange rate of 2%, the volume of water released is still 2.4 times the volume of the draining effluent, and the difference is 18 times at 15% daily exchange.

Although there is a lot of discussion about not exchanging water to minimize the discharge of nutrients and organic matter into natural water bodies, little thought is given to the water discharged at harvest. Assume that a shrimp farmer lowers water exchange to 2% per day as a practice to minimize possible environment effects. The average concentrations of 5-day biochemical oxygen demand (BOD_5) and total dissolved solids (TSS), two important water quality variables in pollution control efforts, are about 5 mg/L and 100 mg/L, respectively, in waters of semi-intensive ponds. Thus, about 120 kg BOD_5/ha and 2,400 kg TSS/ha would be discharged from ponds through water exchange during the crop period.

Near harvest, BOD_5 and TSS concentrations will have increased to about 10 mg/L and 150 mg/L, respectively. When ponds are drained, effluent will be almost identical in composition to pond water until about 80% of the pond volume has been released. During final draining to empty ponds, concentrations of BOD_5, TSS, and other substances will increase because of sediment resuspension caused by crowding of frightened shrimp, shallow and rapidly flowing water, and harvest activities. The average BOD_5 and TSS concentrations often are about 50 mg/L and 1,000 mg/L, respectively, in the final 20% of effluent volume. Thus, the load of BOD_5 is about 180 kg/ha and the load of TSS is around 3,200 kg/ha in the effluent released to empty the pond. The draining effluent contributes more to potential pollution than does water exchange at 2% per day. The following table allows a better assessment of the situation described above.

	Concentration (mg/L)		Load (kg/ha)	
Type of Effluent	BOD_5	TSS SST	BOD_5	TSS SST
Water exchange	**5**	**100**	**120**	**2400**
Draining (first 80%)	**10**	**150**	**80**	**1200**
Final draining (last 20%)	**50**	**1000**	**100**	**2000**
Total	**---**	**---**	**300**	**5600**

The last 20% of draining effluent contributes about 33% of BOD_5 and 35% of TSS released during the entire crop. The final effluent also is many times more concentrated than the water exchange effluent and the initial draining effluent (first 80%).

Settling basins are very effective in removing coarse solids such as those suspended in water during the final phase of pond draining. Also, considerable BOD_5 is associated with the coarse solids. Studies have shown that 60 to 80% of TSS and 15 to 30% of BOD_5 can be removed in a settling basin with only 6 to 8 hours of water detention time. Settling basins offer an excellent method for treating effluent released during shrimp harvest, and especially the final, highly-concentrated effluent.

Settling basins are simply ponds that detain water for long enough time for coarse suspended solids to settle to the bottom. These basins can be 1 or 2 m deep, and water should be introduced at the surface on one side and discharged from the surface on the other side. The size of the basin depends upon the inflow rate and the detention time necessary for removing coarse solids.

Shrimp farmers may think that settling basins will require too much space. However, this opinion is not necessarily true. Consider a 500-ha shrimp farm with 1-m deep ponds operated with an average daily water exchange of 2%. The daily water exchange volume would be 100,000 m^3, and on a day when 20 ha of ponds are completely drained, the effluent volume would increase to only 300,000 m^3 per day. To provide a detention time of 8 hours, a 100,000-m^3 settling basin would be necessary. This would require a 1-m deep settling basin of 10 ha or a 1.5-m deep settling basin of 6.67 ha. These areas would be only 2% and 1.34% of the farm area. Thus, we conclude that widespread use of sedimentation to treat shrimp farm effluents is feasible.

In addition to removing the coarse solids from the final effluent, settling basins also would remove solids from the effluent released during water exchange and in the initial phase of pond draining. This is important because a literature review of shrimp farm effluent (Boyd and Gautier 2000) revealed that total suspended solids are consistently above 100 mg/L. Most water quality permits only allow 50 mg/L total suspended solids, so without sedimentation basins, shrimp farm effluents can be expected to exceed the widely-used effluent permit limit of 50 mg/L.

Settling basins gradually fill in as they accumulate sediment, and detention time for water declines. Thus, settling basins should be constructed 1.5 to 2 times larger than necessary. Even with reserve capacity, settling basins will lose volume as sediment accumulates, and they must be cleared out occasionally to maintain adequate performance. Dual settling basins should be constructed so that one can be in use while the other is being cleaned. However, even if settling basins are constructed in duplicate and with reserve capacity, they still would not require more than 4 to 6% of the area of a large farm. Of course, on a small farm, the proportion of farm area devoted to settling would have to be much larger - often 10 to 20% of farm area. Nevertheless, settling basins seem to be the only practical means of treating effluents from either small or large shrimp farms.

WATER QUALITY STANDARDS

It is not easy to formulate water quality standards for effluents from a previously unregulated activity such as shrimp farming. Standards must be strict enough to provide environmental protection, or those representing environmental interests will object. On the other hand, standards must not be too strict, or shrimp farmers will not be able to comply with them.

A reasonable approach to this problem is to compare water quality concentrations in shrimp farm effluents with water quality limits applied to activities that are currently regulated. This comparison should reveal if some variables in shrimp pond effluents are likely to be outside normally accepted ranges, and suggest the measures necessary to provide a satisfactory effluent. Standards could then be established based on the effluent concentrations that can be expected if shrimp farmers apply the best management practices and treatment methodology that is economically feasible within the industry.

Relatively few organizations have prepared water quality standards for shrimp farm effluents. Although three examples of effluent standards are available for the United States, they were not considered suitable for use here. Water quality standards are commonly formulated for inclusion in permits for discharge of municipal, industrial, and other types of effluents. The usual variables and concentration limits found in effluent water quality standards are provided in Table 4. Shrimp farm effluents will often exceed typical limits for total suspended solids and total phosphorus concentrations. Shrimp farm effluents also may occasionally have pH above 9.0 and dissolved oxygen below 5 mg/L.

Shrimp farms have limited options for effluent treatment. The only economically feasible ways of improving effluent quality appear to be adoption of best management practices (BMPs) and installation of sedimentation basins. Application of BMPs can lower nutrient inputs, reduce sediment resuspension and erosion, and improve dissolved oxygen concentrations. Use of BMPs can also moderate pH and total ammonia nitrogen concentrations in pond waters, with resulting effluents of higher quality. Nevertheless, on many shrimp farms, application of BMPs alone will not be sufficient to lower total suspended solids and total phosphorus concentrations below limits in typical effluent standards. Total phosphorus is associated mainly with suspended particles, and sedimentation lowers both total phosphorus and total suspended solids concentrations.

The Global Aquaculture Alliance (GAA) has developed effluent standards for shrimp farming (Boyd and Gautier 2000). We highly recommend that shrimp farmers attempt to comply with these standards. Compliance with newly developed effluent water quality standards cannot be achieved immediately. GAA will begin with rather liberal effluent standards. These will require participants to demonstrate improvements in effluent quality, and ultimately comply with more restrictive target standards.

Semi-intensive shrimp farms have better-quality effluents than intensive shrimp farms, but the same effluent standards should apply to both types of shrimp culture. It will just be easier for semi-intensive farms to comply with the standards. Initial standards should be at least strict enough to prevent unusually low pH or dissolved oxygen concentration and extremely high concentrations of other variables. The GAA program uses the most liberal limits observed in other permits (Table 4) as the limits in its initial standards (Table 5) for shrimp farm effluents. The limits in the target standards are about the same as those frequently found in effluent permits (Table 4). Although it is common to have a turbidity limit in effluent standards, one was not included in the proposed effluent standards. Usually, if total suspended solids concentrations in aquaculture pond effluents are within acceptable limits, turbidity also will be below the maximum permissible concentration. However, collection of data to verify this generalization would be useful.

Table 4. Water quality variables and their concentration limits found in effluent permits for activities other than shrimp farming.

VARIABLE	USUAL LIMITS	COMMENTS
pH	6.0-9.0	1. Some permits have an upper limit of 8.5 2. A variance allowing afternoon pH of 9.5 is sometimes provided for water treatment pond effluents
Total Suspended Solids	≤ 30 mg/L	Some permits have limits up to 100 mg/L
Total Phosporus	≤ 0.2 mg/L	Some permits allow up to 0.5 mg/L
Total Ammonia Nitrogen	≤ 2.0 mg/L	Some permits allow up to 5 mg/L
5-day Biochemical Oxygen Demand	≤ 30 mg/L	1. Some permits may have an upper limit of 20 mg/L 2. Some permits have an upper limit of 50 or 60 mg/L for water treatment pond effluents
Dissolved Oxygen	≥ 5.0 mg/L	1. Some permits for discharge into high quality water may have 6 mg/L as minimum concentration 2. Some permits for discharge into lower quality water may allow as low as 4 mg/L

Table 5. Suggested initial and target water quality standards for shrimp farm effluents

VARIABLE	INITIAL STANDARD	TARGET STANDARD
pH (standard units)	6.0-9.5	6.0-9.0
Total Suspended Solids (mg/L)	$\leq$ 100	$\leq$ 50
Total Phosphorus (mg/L)	$\leq$ 0.5	$\leq$ 0.3
Total Ammonia Nitrogen (mg/L)	$\leq$ 5.0	$\leq$ 3.0
5-Day Biochemical Oxygen Demand (mg/L)	$\leq$ 50	$\leq$ 30
Dissolved Oxygen (mg/L)	$\geq$ 4.0	$\geq$ 5.0

Water analysis

Water analysis is a highly specialized field and methods for measuring the concentration of almost any possible constituent of water are available. These methods may be found in several standard water analysis manuals. The most widely used of these manuals is the "Standard Methods for the Examination of Water and Wastewater" (Cleoceri et al. 1998). To make water analyses according to standard procedures, a water analysis laboratory and a well-trained analyst are essential. In practical aquaculture, only a few water quality data are needed in making water quality management decisions. These normally include pH, total alkalinity, total hardness, dissolved oxygen, carbon dioxide, and plankton abundance. Water analysis kits that test these variables are available at a modest cost. The kits provide sufficiently accurate data on which to base management decisions. A Secchi disk, which may be constructed from common items or purchased for a small cost, may be used to estimate plankton abundance.

Water sampling

Water samples for dissolved oxygen or carbon dioxide analyses must be collected so that they do not come in contact with the atmosphere. If a sample is supersaturated with dissolved gases, the gases are lost to the atmosphere. A number of samplers are available for collecting water for dissolved gas analyses, but the least expensive types may be obtained from the manufacturers of water analysis kits.

Samples for total alkalinity, total hardness, or pH may come in contact with the air without introduction of appreciable errors in measurement. Samples of surface water may be secured by simply immersing an open-mouthed bottle and allowing it to fill. Samplers may also be constructed for obtaining water from greater depths. For example, a stoppered bottle may be attached to a wooden stick and lowered to the desired depth. The stopper is then jerked out with an attached cord so that the bottle may fill. Once the water sample has been collected it should be analyzed as soon as possible to prevent changes in concentrations of the constituents of interest.

Water analysis kits

The largest and best known manufacturer of water analysis kits is probably the Hach Company of Loveland, Colorado, USA, but kits of comparable quality may be obtained from other companies. In using kits, the directions should be followed carefully and all operations conducted with as much precision as possible. Slight errors in measuring the volumes of samples or titrating agents will be greatly magnified in the final results. For measuring total hardness or total alkalinity on samples with low concentrations (below 20 or 30 mg/L) of these constituents, the volumes of samples and reagents should be increased by five times to get reliable results.

Measurements of pH with water analysis kits are 0.5 to 1.0 pH unit higher than the correct values obtained with a pH meter. The reagents in water analysis kits deteriorate with time and should be replaced every 6 to 12 months. In spite of the limitations of water analysis kits, they are often the only method available for water analysis in shrimp culture, and with reasonable care the kits will provide useful data. In Table 6, comparisons are made between data obtained on the samples by a Hach water analysis kit and by standard laboratory procedures.

Table 6. Comparison of determinations made on water samples by standard methods and a Hach water analysis kit.

PROCEDURE	SAMPLE			
	A	B	C	D
Total alkalinity (mg/L)				
Standard Method	11.0	31.8	49.6	119.7
Hach kit	15.6	33.7	49.4	116.3
Total hardness (mg/L)				
Standard Method	7.7	27.1	53.4	107.5
Hach kit	11.1	32.7	55.7	110.4
Carbon dioxide (mg/L)				
Standard Method	1.2	4.3	10.9	18.0
Hach kit	5.0	5.0	10.0	15.0
Dissolved oxygen (mg/L)				
Standard Method	1.1	2.7	4.9	8.6
Hach kit	2.0	2.8	4.0	8.0
PH				
Standard Method	4.5	5.5	7.8	8.8
Hach kit	5.0	6.1	9.0	9.7

More advanced, and expensive, water analysis kits are available. These kits have the capacity for measuring dissolved gases, pH, ammonia, nitrate, nitrite, phosphate, sulfate, chloride, conductivity, and several other water quality variables. The more elaborate kits are suitable for aquaculture management and for some types of research in aquaculture. Hach Company makes one kit specifically for shrimp farming.

Dissolved oxygen

Dissolved oxygen is probably the most important single variable in aquaculture. Fortunately, measurements of dissolved oxygen are easy to make using polarographic or amperometric sensors and electronic meter. The most popular dissolved oxygen meters in shrimp farming are the several models of oxygen meters marke-ted by the Yellow Springs Instrument Company, Yellow Spring, Ohio, USA.

In semi-intensive shrimp ponds, a minimum of two measurements should be made each day during the growing season. Measurements made at dawn and late afternoon will normally provide information on the daily extremes. Critical dissolved oxygen concentrations usually occur at night, and it is often desirable to make dissolved oxygen measurements during the night in ponds with dense phytoplankton blooms.

Dissolved oxygen concentrations can vary considerably with depth and area location. In shrimp ponds, the lowest dissolved oxygen concentration is usually in the deepest water where the shrimp spend most of their time. Thus, dissolved oxygen measurements should be made in the deep end of the pond and near the bottom. It is important to prevent the dissolved oxygen probe from contacting the bottom or erroneous readings will result. Ideally, the measurements should be made 5 cm above the bottom.

Because of the importance of obtaining reliable dissolved oxygen data in shrimp farming, a discussion of dissolved oxygen meters and their use will be provided. The meter consists of an electrode that produces a current proportional to the tension of oxygen in the water and instrumentation to convert the flow of current to a meter reading that indicates the dissolved oxygen concentration in milligrams per liter. We will discuss operation of the electrode, but not the technique for translating current into milligrams per liter of dissolved oxygen as this is not under control of the operator.

A typical dissolved oxygen electrode, often called a probe, consists of a gold electrode and a silver-silver oxide reference electrode. The electrodes are bathed in 4 M KCl and separated from the sample by a membrane usually made of Teflon (Figure 2). The gold ring is the cathode and the silver pellet is the anode. The membrane is permeable to gases and the rate at which oxygen crosses the membrane is related to the oxygen tension in the sample. When an electrical voltage is applied to the probe, molecular oxygen diffusing across the membrane reacts with the cathode and is reduced to form hydroxide:

$$4e^- + O_2 + 2H_2O = 4HO^-$$

A current then flows to the silver electrode and the hydroxide reacts with silver to form silver oxide:

$$2Ag^o + 2OH^- = Ag_2O + H_2O + 2e^-$$

The silver oxide appears as a black or brown coating on the silver and acts to form a half-cell that completes the circuit with the gold electrode. The sample and the potassium chloride solution bathing the electrodes do not come to equilibrium with respect to dissolved oxygen because oxygen is consumed at the cathode and we may assume that the oxygen tension beneath the membrane is near zero. The force causing oxygen to diffuse across the membrane is proportional to the tension of the oxygen in the sample. Therefore, when the oxygen tension is low, the current flowing between the two electrodes will be less than when the oxygen tension is high.

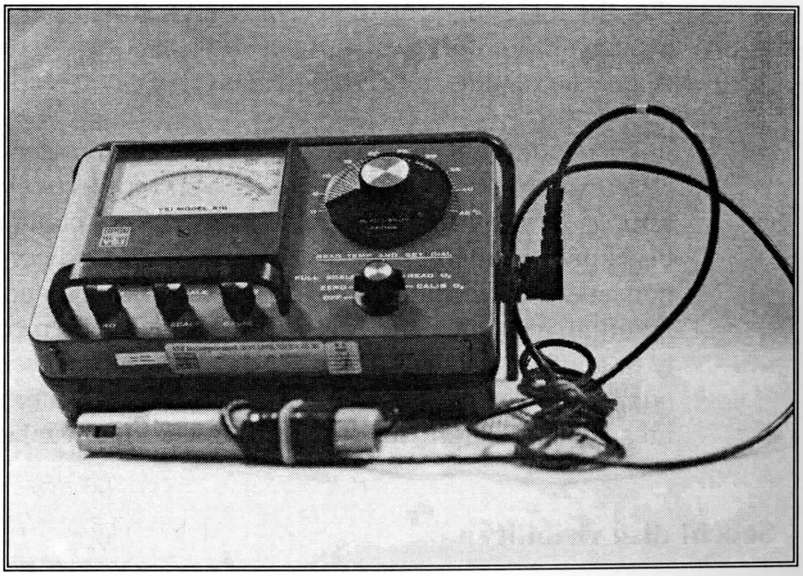

Figure 2. Oxygen meter.

The permeability of the membrane to oxygen is greatly affected by temperature. The current produced by 10 mg/L of dissolved oxygen at 10 °C is only about one-fourth the amount produced by 10 mg/L of dissolved oxygen at 30 °C. A thermistor setting in the electrode circuit automatically compensates for this temperature effect.

Temperature also affects the current flow between the electrodes through the relationship of temperature to oxygen tension. A water saturated with dissolved oxygen at 15 °C and at a pressure of 760 mm Hg has an oxygen tension of 159 mm Hg and contains 9.76 mg/L of dissolved oxygen. If a dissolved oxygen meter is calibrated for this temperature and pressure, it will read 9.76 mg/L of dissolved oxygen when used for the water mentioned above. Suppose the meter is now used to measure the dissolved oxygen concentration of another water at 20 °C and 760 mm Hg that is sa-turated with dissolved oxygen. Because of the higher temperature, this water will contain only 8.84 mg/L of dissolved oxygen, but the meter will still read 9.76 mg/L because it was calibrated to read this concentration at an oxygen saturation at 760 mm Hg or at an oxygen tension of 159 mm Hg. Dissolved oxygen meters are equipped with either automatic or manual temperature compensators to correct this discrepancy. The dissolved oxygen concentration in water at saturation also decreases with decreasing atmospheric pressure and with increasing salinity, so most meters are also equipped with manual pressure (altitude) and salinity compensators.

The most reliable readings are obtained for waters that contain dissolved oxygen concentrations between 2 mg/L and the concentration of dissolved oxygen at saturation for the particular water temperature and atmospheric pressure. Readings obtained for waters with very low concentrations (both in milligrams per liter and in tension) of dissolved oxygen and for waters supersaturated with dissolved oxygen are only approximate. It is imperative that the meter be properly calibrated for the local atmospheric pressure, the electrode be properly fitted with a clean membrane, and any manual temperature and salinity compensations be made before taking dissolved oxygen readings.

It is often desirable to check dissolved oxygen meters to determine if they are giving accurate readings. This can be done on a shrimp farm by an approximate method. Saturate a sample of distilled water with oxygen, "air calibrate" the dissolved oxygen meter as explained in the manufacturer's instructions, and compare the measured dissolved oxygen concentration to the theoretical dissolved oxygen concentration for the appropriate temperature. It is difficult to bring the dissolved oxygen concentration in a water sample exactly to equilibrium with atmospheric oxygen. However, an approximate equilibrium can be attained by slowly stirring a sample of distilled water in a clean container for 15 or 20 minutes and then letting it stand undisturbed for a few hours.

Secchi disk visibility

As mentioned in the section, "Measuring Productivity," a Secchi disk is 20 cm in diameter, painted with black and white quadrants, and attached to a calibrated line. The disk is weighted on the underside with a lead plate so that it will sink readily. Secchi disks may be purchased from scientific supply houses or constructed from sheet metal, Plexiglas, or masonite. A flat paint should be used to prevent glare. A suitable alternative to attaching the disk to a calibrated line is to attach it from its center to a vertical meter stick. Secchi disk visibilities seldom exceed 40 or 50 cm in productive aquaculture systems, so measurements will seldom be limited because of the length of the meter stick.

Secchi disk visibility is not a suitable estimate of plankton unless plankton is the primary source of turbidity. An experienced observer can readily distinguish between plankton turbidity and other forms of turbidity. However, the novice must remember that plankton blooms are not always green. Plankton blooms may also impart yellow, red, brown, or black coloration to water. Usually plankton organisms are large enough that their particulate nature is obvious if water and its contents are viewed against a white background.

To obtain the Secchi disk visibility, lower the disk into the water until it just disappears and record the depth. Lower the disk a little more and then raise it until it just reappears and record the depth. In making these measurements, view the disk from directly above. The average of the two depth readings is the Secchi disk visibility. Conditions for taking Secchi disk measurements should be standardized. A good practice is to make measurements on calm days between 9 a.m. and 3 p.m. If possible, make readings when the sun is not behind clouds. Make measurements on the lee (downwind) side of the boat with the sun behind you.

Even when conditions are carefully standardized, Secchi disk visibilities obtained at the same time by different observers for the same body of water will vary slightly. Furthermore, the same observer may obtain slightly different readings if the disk is viewed in the same pond at different times of the day. In practice these slight variations are not critical. In the absence of a Secchi disk, any white object or even the palm of your hand can be used to judge turbidity in pond waters.

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Shrimp culture is growing economic activity in Central America that is estimated to benefit an estimated 30,000 residents, in Honduras and Nicaragua alone, in coastal communities affected by sub- and unemployment. In coastal areas where land is marginal in terms of agricultural production and where fishing is on the decline, aquaculture may be one of the best alternative sources of income. Long-term sustainability of this activity depends on responsible use of coastal resources and good management of sensitive coastal habitats where shrimp farms are located. Improved use of inputs, reduction of risks and better farm management are also critical if small and medium scale farms are to succeed.

Hurricane Mitch severely impacted coastal areas in Central America in 1998, damaging shrimp farms and destroying the shrimp crop. To aid in recovery of this important sector, the Integrated Regional Shrimp Farming Initiative of the United States Department of Agriculture (USDA) was created to develop Best Management Practices for small and medium scale shrimp producers and deliver training programs in the implementation of these practices.

This manual is one product of this program and was the result of the collaboration of 8 universities and multiple governmental and private sector experts who have provide extensive guidance in the latest methods for improving the efficiency of shrimp farming with particular emphasis on small and medium farms. These methods include both business management and technical aspects. Careful attention is also given to identifying critical points at which farmers can take steps to prevent potential environmental impacts which may be associated with the activity. The result is a comprehensive approach to improving farm efficiency, reducing risks and managing the natural resources on which shrimp farming depends

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